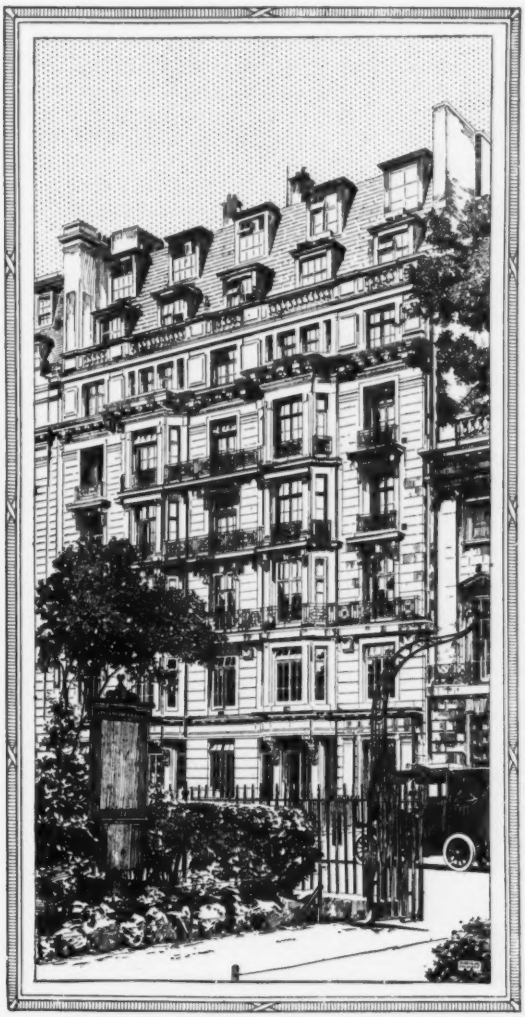
The ENGLISH ELECTRIC JOURNAL



Queen's House from Lincoln's Inn Fields.

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One of four Three-phase Banks of 110,000-volt, Single-Phase Transformers recently completed for India.

The English Electric Journal

Vol. III. No. 4 JANUARY/MARCH, 1926 One Shilling

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All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, QUEEN'S HOUSE, KINGSWAY, LONDON, W.C.2.

EDITORIAL.

The major portion of this issue of the Journal is devoted to Transformers, the manufacture of which forms an important part of the Company's business. The Company's Stafford Works have been engaged in this manufacture since the year 1904, and transformers of the Company's make totalling many thousands of kilowatts are now in service in all parts of the World. In this connection it is of interest to note that the oil conservator, which is now so generally used with large transformers, was introduced into this country by the Stafford Works.

In recent years the transformer business of the Company has greatly extended, and to meet the increased demand further facilities for manufacture have had to be provided. Advantage has been taken of this opportunity to introduce the very latest and most efficient methods of manufacture, and the new Shops and plant represent the most complete equipment of the kind that can be found. Further, the designing staff has been strengthened by the addition of English Engineers with many years' experience abroad in the design and manufacture of transformers of the largest size, and of the highest voltages employed.

The transformers made for the Tata Companies in India, which are described in one of the ensuing articles, will be found to be of particular interest on account of their size, and of the abnormally high test pressure that they have to stand. Further, the strength of the mechanical construction, the special arrangements to permit of uniform cooling throughout the transformers, and the methods of winding and insulating the coils, are especially worthy of note. In another article our standard types of transformer

for power transmission purposes are described, and an article is also devoted to the large Shell-type Transformers that have recently been supplied to the City of Liverpool.

The perusal of the articles will, we believe, make it clear to our readers that large transformers, even for the highest voltages, can be made thoroughly sound engineering structures, and that, in fact, from the point of view of mechanical strength and soundness of construction, they can rank with any class of engineering products. This is only as it should be, for with the ever increasing outputs of generating plants the stresses to be met with under short-circuiting conditions are very great indeed, and demand a thoroughly sound mechanical construction if security in operation is to be assured.

Transformers of all sizes, and for all voltages and conditions of service, are manufactured by the Company.

Having dealt with transformers we would next draw attention to the complete electrification of the new Plate Mill laid down by the Consett Iron Company, which is described in one of our articles. The total capacity of the plant supplied by the Company for this purpose amounts to some 60,000 kilowatts and includes Turbo-Generators, Rotary Converters, Transformers, and complete Switchgear and Control apparatus, in addition to the driving motors themselves. The motors include two reversing units, each of 14,000 H.P. at 50 R.P.M., one light Plate Mill Motor of 2,500 H.P. and one Chequer Plate Mill Motor of 1,500 H.P., while, in addition, all the necessary motors for driving live rolls, screwdown gear, mangles, cranes, etc., were installed, the total number of auxiliary motors supplied in conjunction with the equipment being over 280. Such a plant naturally presents many features of interest, both mechanical and electrical, and not the least notable is the method of control of the large reversing motors. This is effected through the agency of a remote-controlled oil servomotor, which enables the most rapid control of the whole equipment to be effected with great simplicity and with the minimum of effort and fatigue to the operator. Since setting to work, this device has operated with great satisfaction, and the ease of control has been a considerable item in the very satisfactory results that have been obtained.

The English Electric Company Limited has specialised in Rolling Mill work for many years, the first large equipment, which had a peak load of 12,000 H.P., having been manufactured in 1910. Since that date a total of 130,000 H.P. in large reversing mill motors has been supplied, and an approximate total of 200,000 H.P. for other Rolling Mill drives.

This issue of the Journal also contains a description of a multiple-unit equipment for the operation of tramways and light railways. This is a development from the Company's well-known camshaft multiple-unit control for heavy railway work, and is proving of great use where a "rush-hour" service, or an increased service of any kind has to be handled. Putting more cars on the line has the disadvantage of reducing the headway between cars, while the use of trailer cars reduces the scheduled speed of working, and the natural solution of such difficulties is to employ a second car, completely equipped, but operated from the master controller on the leading car.

110,000-Volt Transformers for 100,000-H.P. Transmission Scheme.

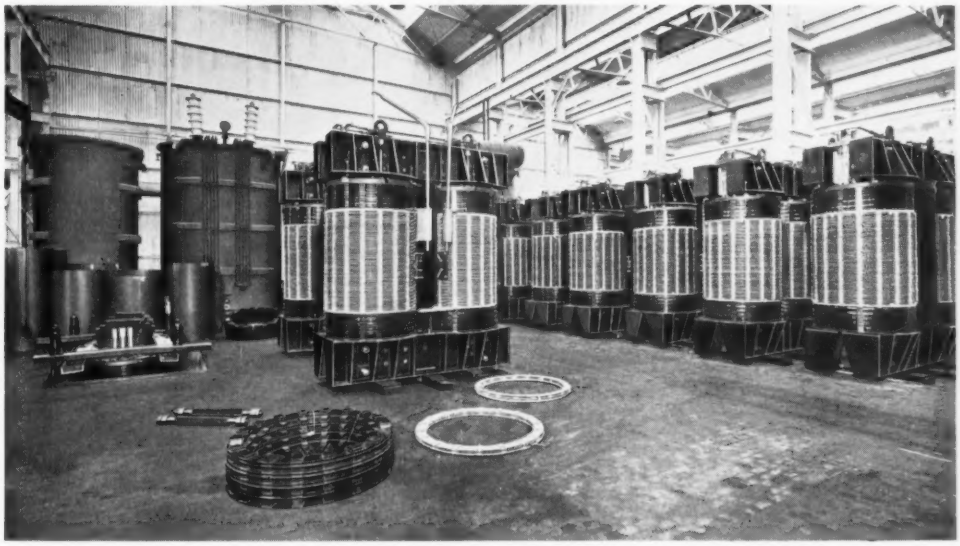


FIG. 1. A CORNER OF THE TRANSFORMER ERECTING SHOP, STAFFORD, CONTAINING 150,000 KVA. OF 110,000 VOLT TRANSFORMERS.

The largest and most recent of the enterprises planned by the Tata Companies for the supply of electrical energy to Bombay and its environs, provides for the construction of a Hydro-Electric Power Station at Bhira, and the transmission to the city by an overhead line about 75 miles long, of some 100,000 H.P.

In this important scheme, which is now well advanced towards completion, power will be generated at 11,000 volts, 50 cycles, 3 phase, stepped up to 110,000 volts for transmission, and transformed down to 23,000 volts for the main distribution in Bombay and the surrounding districts.

At the Power Station there are four banks of transformers, each bank consisting of three single-phase units and having an output of 30,000 KVA. The high-voltage windings are arranged for star connection with solidly and permanently grounded neutral, and advantage has been taken of this condition to use graded insulation in the transformers. One end of the H.V. winding is connected to an outlet bushing and the other end is connected to the transformer core. The test that is applied to a transformer designed in this manner can be only an induced voltage test, the value of the test voltage being 2·73 times the normal voltage to ground, making the test figure in this case 173,000 volts. The test is, of course, carried out with one end of the winding grounded.

At the Receiving Station in Bombay there are four banks of transformers, each bank having an output of 27,000 KVA. and consisting of three single-phase units. The high-voltage windings are connected in delta and the test from the H.V. winding to the L.V. winding and ground amounted to 240,000 volts. The

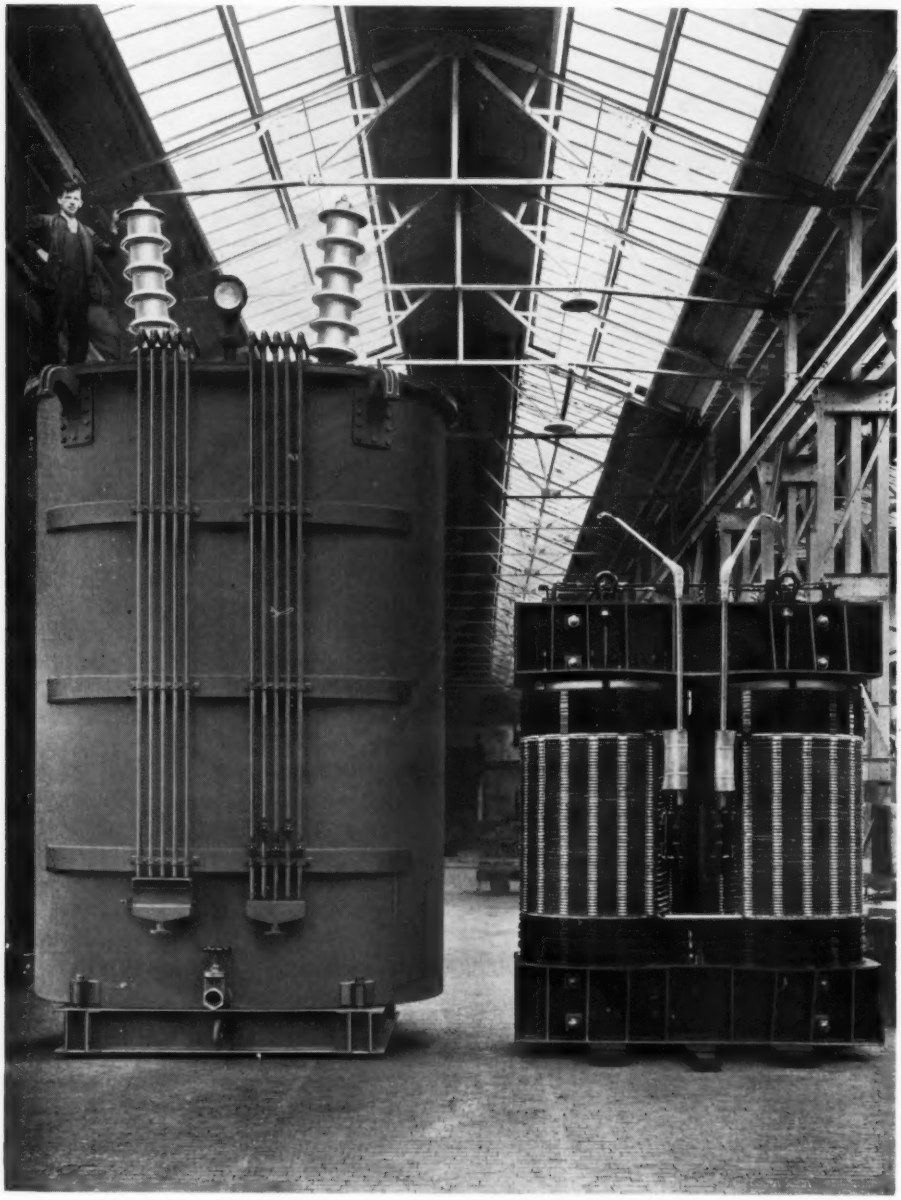


FIG. 2. 110,000-VOLT, SINGLE-PHASE TRANSFORMER; 50 CYCLES, 12,500 KVA. WATER-COOLED.

problem of insulating these transformers is obviously very much greater than in the case of star-connected windings with the neutral solidly grounded.

The manufacture of the Receiving Station transformers was entrusted to The English Electric Company Limited, and was carried out at the Stafford Works of the Company. In the following pages is a description of the main features of the design of these units, which rank amongst the largest transformers manufactured in England up to the present time.

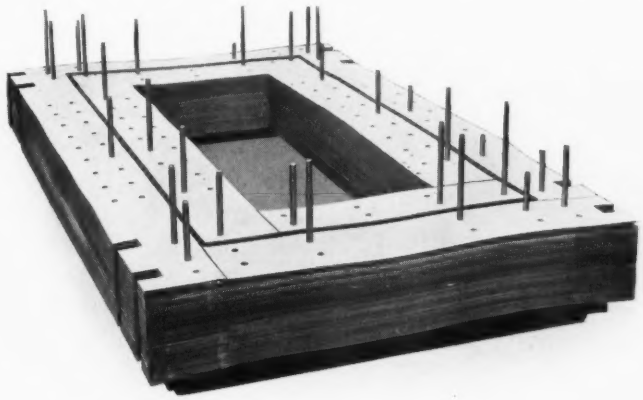


FIG. 3. BUILDING THE CORE. THE INTERNAL OIL DUCT AND KEY BOLT NOTCHES ARE CLEARLY SHOWN.

The transformers are of Core-type construction with the windings on two vertical limbs. They are Oil-Immersed, Water-Cooled by means of an internal cooling coil, and arranged for Outdoor Service.

The core is built of laminations of high-grade silicon steel, each lamination being coated on one side with a thin layer of a composition that does not deteriorate with heating.

On account of the large cross-sectional area of the core it was necessary to provide for some internal cooling. Hitherto when this was necessary the usual method was to provide oil ducts in the plane of the laminations, but unless many such ducts are provided this method is of little value, for the reason that the efficiency of heat transmission through a packet of laminations is very poor, due to the large number of imperfectly connected surfaces in series. The correct position for an oil duct in such a core is clearly at right angles to the laminations, so that the heat is transmitted along the plane of the laminations instead of across it.

This design has been adopted in the core in question, and the arrangement of the duct is well illustrated in Fig. 3 and the plate facing page 150. A $\frac{3}{4}$" duct is provided completely round the core, thereby converting it virtually into two separate cores, one concentric with the other. In order to close in the duct, and also to connect together the two cores, the outer packet of laminations (the core being of double cruciform section) is left solid and by means of a number of insulated core bolts and an external clamping plate the two cores are bolted rigidly together. In order that the oil may gain entrance to and exit from the duct a small portion of the laminations is cut away in the outer packet of the bottom and top yokes.

This core design undoubtedly gives extremely efficient cooling with the best economy of space, and results in a very strong mechanical construction.

Another interesting feature in connection with the core construction is the method of yoke and main frame clamping, which is that adopted as standard for all " English Electric " transformers, and described as the " key-bolt "

construction. The yoke laminations are interleaved with the limbs and in the four outside corners of the core are rectangular notches, in which are placed heavy square bolts which key the yoke and limb laminations together, and serve also to clamp the main frames to the yokes. The main frames are made up of welded steel plate, and as will be appreciated by reference to Fig. 4, this form of construction has resulted in the maximum of strength with the greatest economy of material. Another advantage of this design of core clamping is that the transformer can be lifted entirely from the top main frame, and no vertical tie-bolts are required between the top and bottom frames: the elimination of tie-bolts extending the full length of the windings is obviously a very valuable feature on a high-voltage transformer.

FIG. 4. CORE AND BOTTOM FRAME. TOP YOKE TEMPORARILY ASSEMBLED, AND KEY BOLTS IN THEIR NOTCHES.

Fig. 4 illustrates clearly the construction of the core and bottom main frame, as well as the arrangement of the notches and key-bolts, and the insulation between them.

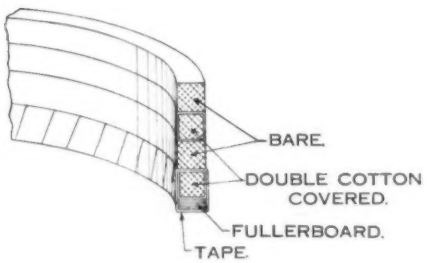


FIG. 5. DIAGRAMMATIC SECTION OF ONE TURN OF L.V. WINDING.

Fig. 6 illustrates a complete L.V. coil for one limb of the transformer. The composite conductor consists of four rectangular wires, alternately bare and double-cotton covered, lying side by side parallel to the axis of the coil. The insulation between turns is provided by a fuller-board strip taped to one of the wires as indicated in Fig. 5. The foundation of the coil is a bakelised paper cylinder, on which the composite conductor is wound in two layers with a sheath of insulation between them. Oil ducts are formed on both sides of each layer of winding by inserting vertical fuller-board

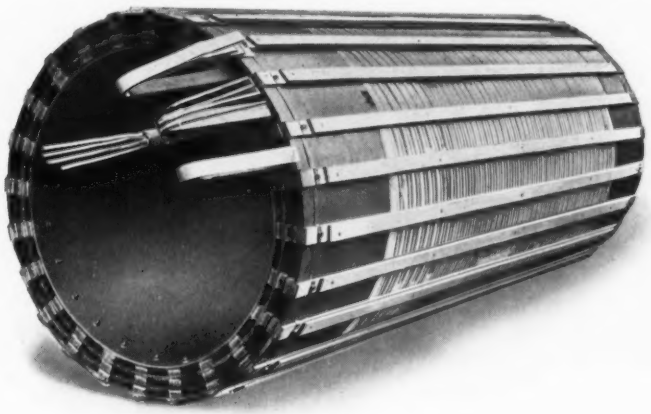


FIG. 6. L.V. COIL SHOWING VERTICAL SPACERS AND SUPPORTING COLLARS.

spacers, which extend to the full length of the coil, inclusive of the supporting collars at the top and bottom.

The method of supporting the winding in the axial direction is interesting. At each end of each layer of winding is placed a collar which is cut from a bakelised paper cylinder formed to the same dimensions as the layer of winding itself. The collars are shaped on the winding side to the spiral form of the winding, and the extreme ends of all the collars are flush and at right angles to the axis of the coil. Through the ends of the vertical spacers and the collars, brass bolts are inserted for the purpose of keeping the spacers and collars in position.

The design of coil just described gives very efficient cooling and also great mechanical strength to resist the effects of short circuits. Each coil has two tappings in addition to the start and finish leads, and all leads are at the upper end of the coil, and are heavily insulated with bakelised paper sleeves where they leave the winding. The finish lead is anchored very effectively by being brought out underneath the outside collar.

The H.V. winding on each limb consists of a number of single-section disc coils arranged in a column with a fuller-board washer and oil duct between each pair of coils. The two columns of coils are connected in series by a connection at the bottom, which can be seen in Fig. 8.

The conductor is a flat wire with half round edges, encased in a sleeve of insulation consisting of layers of paper, specially treated cloth, and cambric, the latter being largely a mechanical protection to the paper and treated cloth. The sleeve is folded on to the conductor while the coil is being wound and is held in place with a spiral of cotton tape. In addition, a fuller-board strip is inserted between turns, as shown in Fig. 7, which illustrates the arrangement of several adjacent turns. In those coils which have specially reinforced insulation between turns, the number of layers of material in the sleeve is increased, and also thicker strips of fuller-board are used.

Fig. 9 illustrates several typical high-voltage coils. "A" representing the coils connected

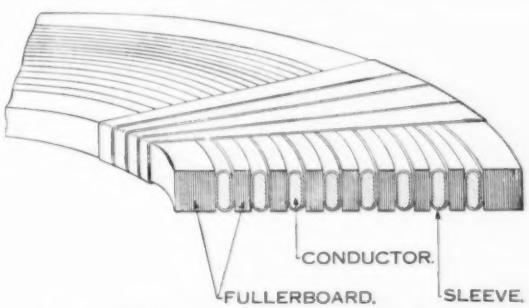


FIG. 7. DIAGRAMMATIC SECTION OF H.V. DISC COIL.

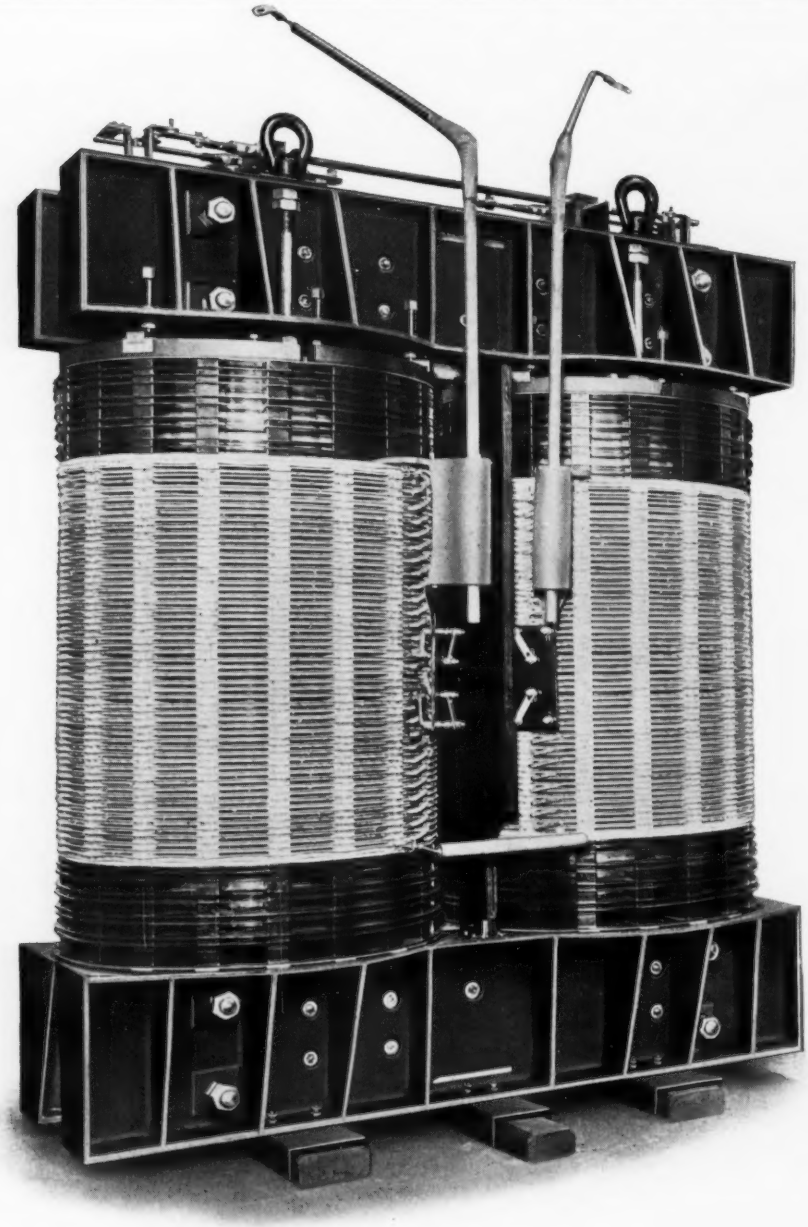
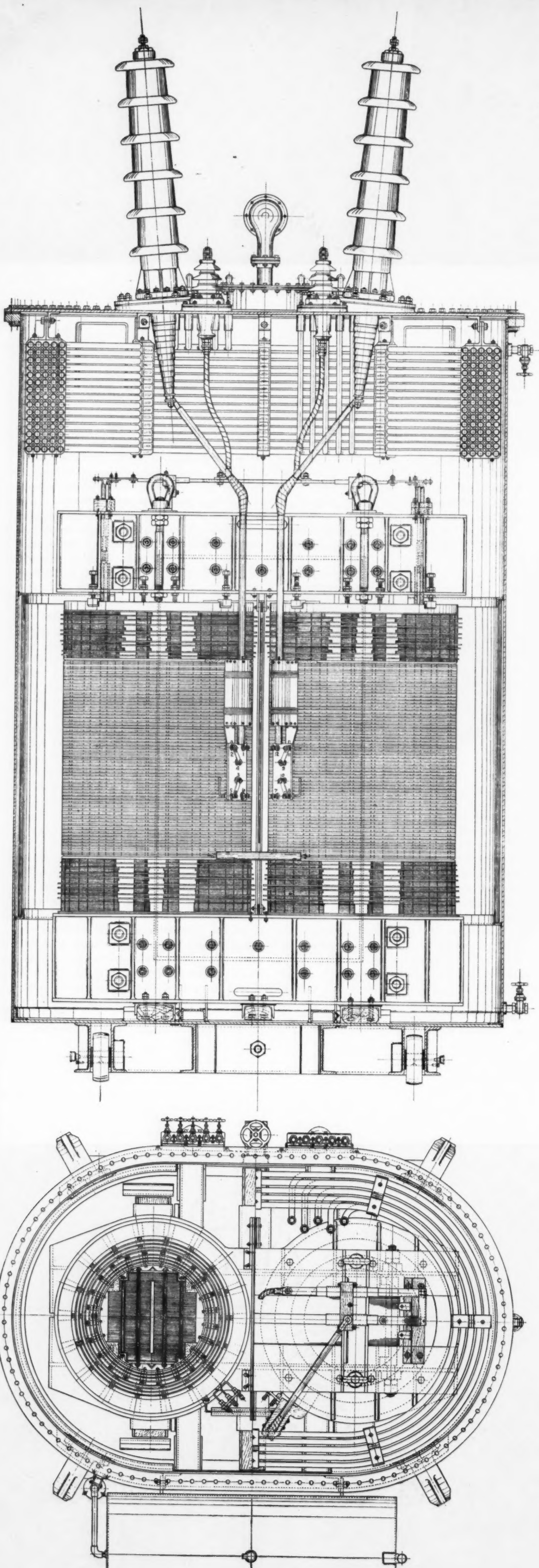


FIG. 8. CORE AND WINDINGS COMPLETELY ASSEMBLED.



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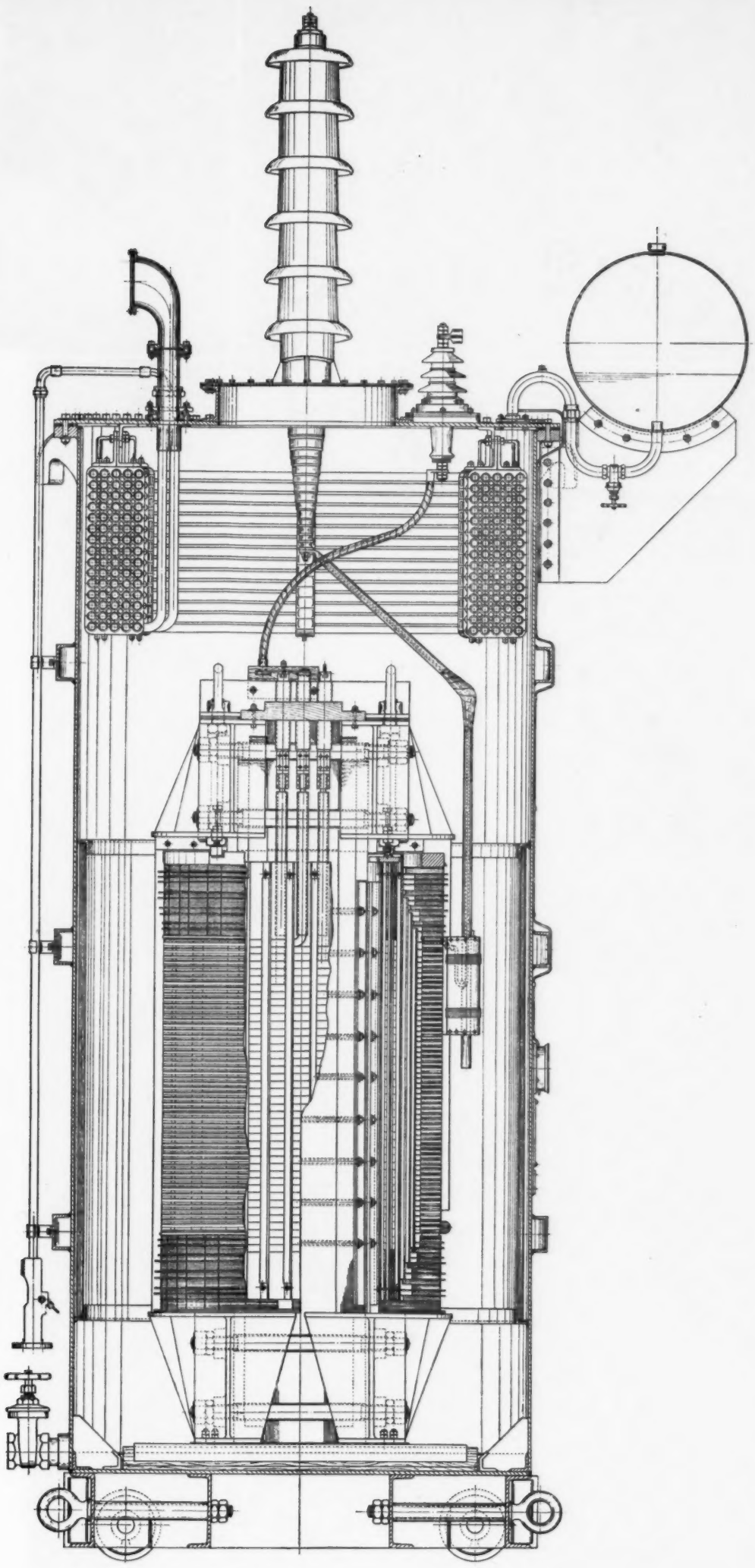

"ENGLISH ELECTRIC"

SINGLE PHASE TRANSFORMER

110,000 VOLTS

50 CYCLES. 12,500 KVA.

OIL IMMERSED. WATER COOLED.

The ENGLISH ELECTRIC Company Limited

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directly to the line, and "B" the coils in the body of the winding. Several coils of the various types were tested, and it was found that the line coils withstood a test pressure of 76,000 volts between adjacent turns, and the coils in the body of the winding 35,000 volts. As the test pressure was applied for a period of approximately three seconds, whereas the usual high-frequency surge that occurs on a high-voltage transmission line is of only a few cycles duration, these results indicate a high factor of safety. The normal working pressure between adjacent turns is only 70 volts.

An important feature of the design is the ample provision which has been made for the circulation of oil, so that every wire throughout the transformer is exposed to oil. In this way the temperature gradient between any point in the copper and the oil is maintained at a very low value.

The windings are arranged concentrically, the L.V. winding being next the core. The insulation between the H.V. and L.V. windings consists of four concentric bakelised paper cylinders which are spaced from the windings and from each other by a number of vertical fuller-board spacing strips, thus forming oil ducts between adjacent strips.

The top and bottom ends of the H.V. windings are insulated from the yokes by a system of bakelised paper washers and blocks which give the necessary creepage distance. Each of the four sets of this insulation, two on each leg, is bakelised into a solid mass as shown in Fig. 10 which illustrates how this main insulation is arranged.

Between the two columns of coils is placed a heavy vertical barrier of insulation which allows a clear oil duct on each side, from the barrier to the winding.

When the windings and insulation were completely assembled they were clamped down and subjected to heat treatment for several days, in order to take out the shrinkage. Approximately 10 per cent. of the original height of the column was taken out in this manner, and it is extremely unlikely that any further shrinkage will take place in service. The windings are finally clamped by a heavy steel ring placed on top of the main insulation and held down by means of bolts passing through the top main frame. See Fig. 8.

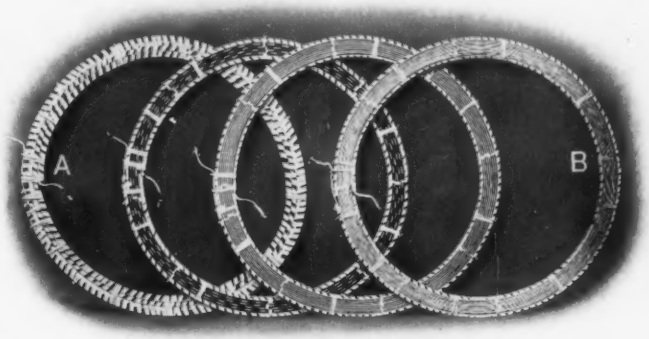


FIG. 9. H.V. COILS. "A" TYPICAL LINE COIL, "B" COIL IN THE BODY OF THE WINDING.

Three different voltages are provided for, and for each voltage tappings are taken from both columns of coils in order not to unbalance the two limbs. Furthermore, the tappings are located in the middle of the column of coils in the usual way, but in addition, a very interesting feature is incorporated; Fig. 11 (a) indicates the arrangement. For each voltage a tapping is taken from the winding on each side of the centre line of the column, and these are connected together in the manner shown, which results in the two small sections of the winding being connected in parallel. It

is obvious that this arrangement maintains the magnetic centre of the winding under any connection. The scheme also has another very valuable feature that is made clear by referring to Fig. 11 (b), which shows the usual method of connecting tappings. With that arrangement every connection except the one for the maximum voltage results in an idle portion of winding. In the event of a high-voltage surge coming into the transformer, it might possibly travel through the winding until it reached the tapping point, where a certain portion of it would pass straight along through the idle winding to the dead end where it would be reflected, and on the return path its damaging effect might actually be increased. With the new scheme of connections, Fig. 11 (a), the whole winding is always in circuit, and there are no points from which it is possible to get any reflected wave. This arrangement necessitates twice as many tappings per voltage as would otherwise be necessary, but the advantages gained are certainly worth while on a big high-voltage transformer.

The leads from the two ends of the H.V. winding are brought up by means of flexible cable encased in heavy bakelised paper tubes to a point close to the lower tips of the H.V. bushings. These leads are supported entirely from the main insulation of the H.V. winding, which ensures that throughout their length there is ample clearance from any grounded portion of the transformer.

The L.V. leads are brought up from the coils at the extreme ends of the transformer between the top main frames, and the connections from the ends of the windings to the L.V. bushings are made by heavy flexible copper cable. The two coils are connected in series and provision is made for three voltages by means of tappings arranged symmetrically on both coils, as shown diagrammatically in Fig. 12. The connections for the various combinations of tappings are made by copper bars situated above the top yoke.

The tank has flat sides joined by semi-circular ends, and is made of $\frac{1}{2}''$ boiler plate with welded seams, the flat portions being stiffened by channel sections welded to them on the outside. For the bottom plate, which is welded to the sides, $\frac{3}{4}''$ material is used and reinforcement is introduced by means of an angle that runs completely round the joint inside, and is welded to the bottom and the sides; additional stiffening is provided by means of internal cross channels, welded to the

FIG. 10. WINDINGS PARTIALLY ASSEMBLED.

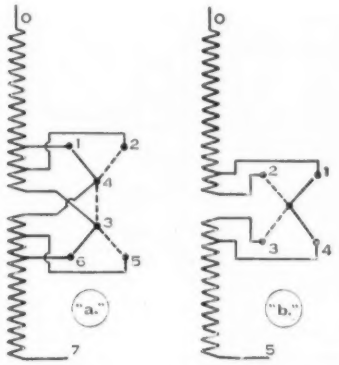


FIG. 11. H.V. TAPPINGS; "a" METHOD EMPLOYED, "b" USUAL METHOD.

bottom, and gusset plates welded to these channels and to the sides of the tank. This construction makes the tank strong enough for the complete transformer filled with oil, to be lifted by means of lifting lugs attached to the top of the tank sides; these lugs are of cast steel, and are riveted and welded to the side plates. Any possibility of oil leaking along the rivets is prevented by a steel cover plate welded to the inside of the tank so as completely to enclose all the rivet heads: a device which renders it unnecessary for the rivets themselves to be made oil-tight.

Round the top of the tank is welded a very stiff steel rim to which the flat boiler plate cover is bolted by a large number of bolts, and an oil-tight joint is formed at this point so that the tank may be completely filled with oil.

In order to allow for the expansion of the oil, an expansion vessel is mounted on the tank side and connected to the main tank by a pipe through the tank cover. In this pipe is a valve which is used to retain the oil in the expansion vessel when it is necessary to open up the main tank. A calcium chloride breather is fixed to the tank and connected to the expansion vessel.

In order to provide a safety valve in the event of a sudden increase of pressure in the main tank, the tank cover is fitted with a funnel-shaped pipe having its outer end closed by a thin sheet of copper which would give way under excessive pressure, and thus prevent damage to a joint elsewhere in the transformer. The opening of the safety valve is above the highest oil level in the expansion vessel.

In the centre of the cover is a large manhole by means of which access can be gained to the tank when the cover is in place.

For draining off the oil a large brass gate valve is fixed at the lowest point of the tank, and there are also smaller valves at the top and bottom to allow for the connection of an oil purifying outfit.

The tank rests on a separate under-base constructed of welded structural steel, which is provided with flat wheels to enable the transformer to be run along a track formed of channel iron.

The Frontispiece and Figs. 2 and 16 illustrate clearly the design of the tanks and the arrangements of the various fittings.

The transformer oil is cooled by means of a water cooling coil suspended from the underside of the tank cover, in the manner shown in Fig. 14. This coil is made of solid drawn copper tube with sleeved and brazed joints, and the separate turns are supported in castings of an aluminium alloy; it consists of five sections

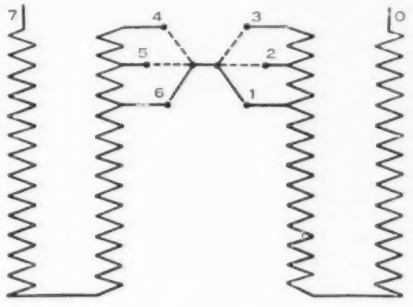


FIG. 12. ARRANGEMENT OF L.V. TAPPINGS.

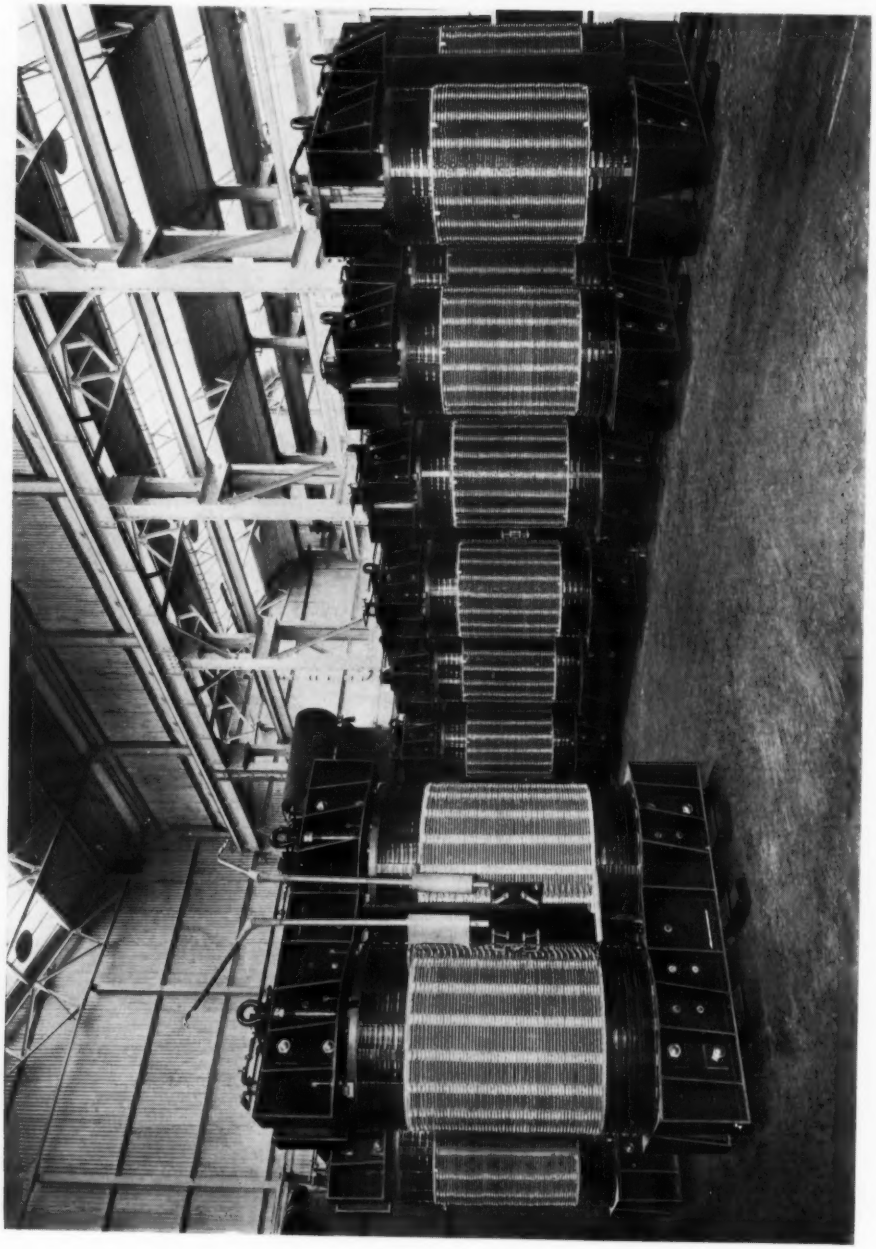


FIG. 13. COMPLETED CORES AND WINDINGS IN THE TRANSFORMER SHOPS, STAFFORD WORKS.

connected in parallel, and this arrangement reduces very considerably the pressure required for circulating the requisite quantity of water. The inlet and outlet pipes from each section are brought through oil-tight glands in the tank cover, and the ends are reinforced at this point by brass tube brazed over the copper pipe.

The external piping arrangement, which can be seen very clearly in Fig. 2, is of wrought iron and is connected to the brass tubes by means of heavy unions. Each section of the cooling coil is controlled by a valve fitted in the incoming pipe near the floor level. The outlet pipes of the five sections are led into an open manifold, where it is possible to see that the water is flowing properly through each section, and in the manifold there is fitted a device for closing an electric circuit for the purpose of operating an alarm should the water supply fail.

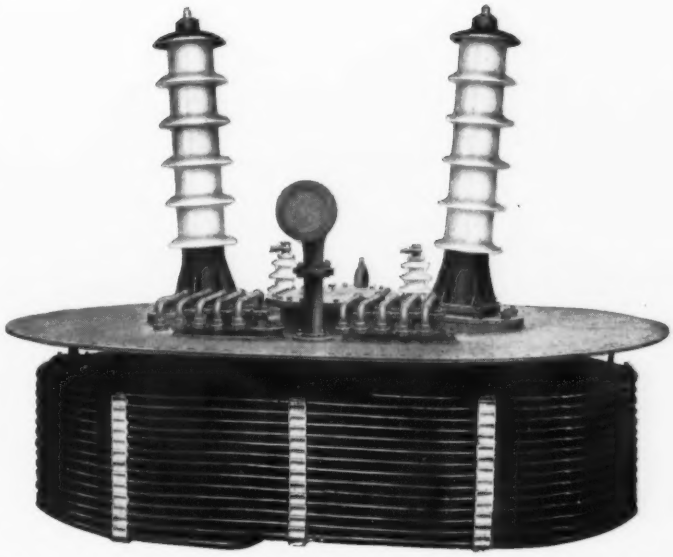


FIG. 14. WATER COOLING COIL SUSPENDED FROM THE TANK COVER.

The L.V. Bushings are made entirely of porcelain and are shaped in such a way as to give the necessary creepage to ground in rainy weather.

The H.V. bushings, one of which is shown in Fig. 18, are of the usual condenser type, with the portion outside the tank encased in a series of porcelain rain shields which give suitable protection for outdoor service. When dry, these bushings would flash over at a pressure of approximately 350,000 volts; under rain conditions the corresponding flash-over pressure would be 250,000 volts.

A dial-type thermometer is mounted on the side of the tank at a convenient height and is connected by capillary tubing to the bulb which is fixed inside the tank at a height corresponding to the hottest oil.

Underneath the thermometer dial there is mounted an engraved brass plate which shows the transformer rating, diagram of connections, and table of voltages. The arrangement and details of the diagram plate and thermometer can be seen from Fig. 15.

Because of the climatic conditions in Bombay, these transformers are designed for a comparatively low temperature rise. On the basis of the standard B.E.S.A. rating for water-cooled transformers, which permits a rise of 65° C., as measured by resistance and corrected to the instant of shut down, the output of each of these transformers would be 12,500 KVA., making the capacity of each three-phase bank 37,500 KVA., or the total capacity of the complete substation 150,000 KVA.

The insulation tests to which the transformers have been subjected are abnormal. The insulation test from the H.V. winding to the L.V. winding and ground was 240,000 volts for one minute. On the over-potential test a

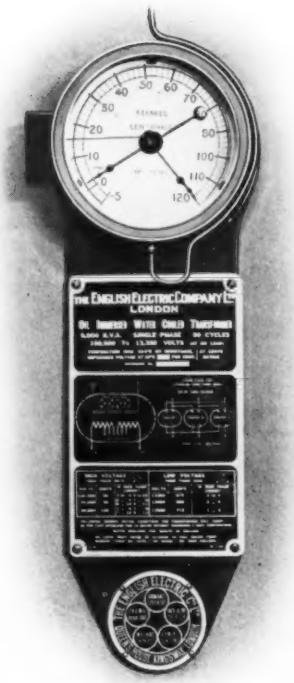


FIG. 15. DIAGRAM PLATE AND THERMOMETER.

voltage of 2·2 times the normal voltage was developed in the winding for one minute, after which the voltage was reduced to 1·65 times normal for 5 minutes.

Before being tested, each transformer was thoroughly dried in a steam heated vacuum tank, and hot oil was allowed to enter before the vacuum was broken. In this way the transformers were thoroughly impregnated with oil, which had previously been carefully dried by means of a centrifugal oil purifier.

The total weight of each core with its windings is 46,000 lbs., the weight of the tank complete with all its fittings, 26,000 lbs., and each unit requires 4,000 gallons of oil weighing 35,000 lbs. Thus, the total weight of the complete transformer is 107,000 lbs. or 48 tons.

The floor space occupied by the tank is 11 ft. by 8 ft. The height over the cover is 16 ft. and the height over the bushings 22 ft. In order to lift the core and coils from the tank the height necessary from the crane hook to the floor is 33 ft.

Obviously, it was impossible to ship these transformers in their own tanks. The tank was packed for shipment lying on one of the half-round ends in a special cradle, and all the fittings were removed and packed separately. The various H.V. and L.V. leads were removed, and an exceedingly strong wooden case was built round the core and coils in such a way that the lifting lugs mounted on the top frame of the transformer projected through the top of the case.

FIG. 16. TRANSFORMER TANK AT THE BRITISH INDUSTRIES FAIR, BIRMINGHAM.

Before putting the transformers into service, it is necessary to dry them out on site. This is done by building a fireproof housing round the core and coils and blowing hot air through this housing. Baffles are provided to direct the flow of hot air in the most efficient manner, and at the same time current is circulated in the windings. Careful observations are made of the temperature of the windings, both by the resistance method and by thermometers placed in various positions.

The period of time required for this drying-out process depends very largely on the atmospheric conditions at the time. When it is considered safe to put the transformer into service, it is put into its own tank which is immediately filled up with hot oil that has been thoroughly purified.

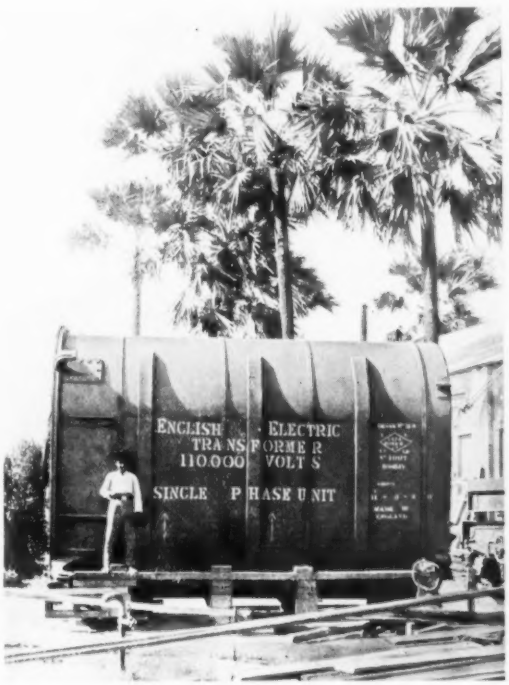


FIG. 17. UNLOADING TRANSFORMERS AT THE RECEIVING STATION NEAR BOMBAY.

FIG. 18. H.V. BUSHING.

In Fig. 16 is reproduced a photograph showing one of the transformer tanks on the stand of The English Electric Company Limited at The British Industries Fair, held recently at Birmingham.

Fig. 17 is from a snapshot recently received from India and depicts the unloading of the transformers near Bombay.

10,000-KVA. Banks of 33,000-Volt Transformers for Liverpool Corporation.

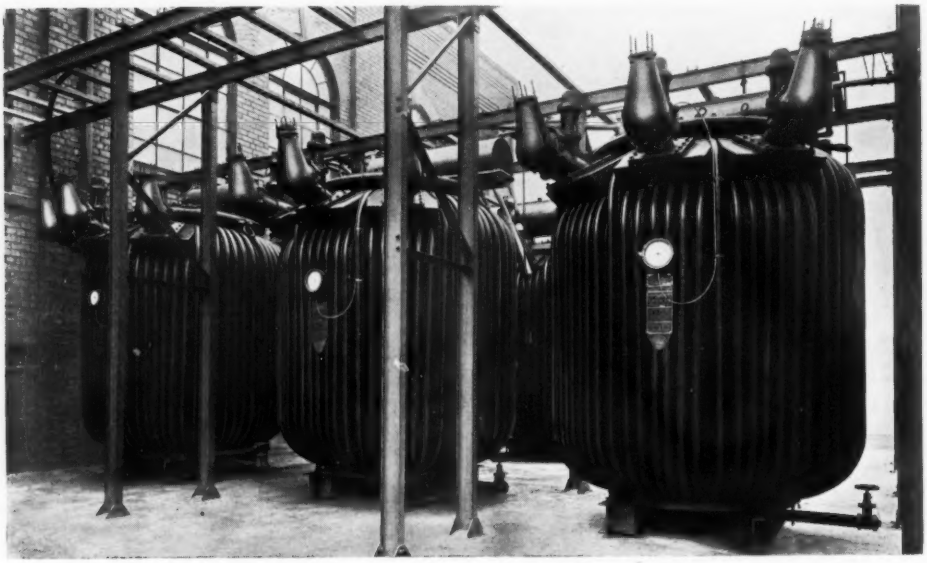


FIG. 1. TWO 10,000 KVA. BANKS IN COURSE OF INSTALLATION AT MARSH LANE SUBSTATION.

The Liverpool Corporation Electricity Department, under the able administration of Mr. H. Dickinson, M.Inst.C.E., M.I.M.E., M.I.E.E., are now making considerable extensions to their plant for the supply of electric power in the Liverpool area. At their Lister Drive Power Station three-phase energy is generated at 6,600 volts, 50 cycles, and will be transformed up to 33,000 volts for transmission by means of underground three-core cables to several substations in the outlying districts. One of these substations at Marsh Lane, about 4¼ miles from Lister Drive, is of the Outdoor type, and is intended to cope with a large development of industry in the Bootle area. The order for the transformers for this substation was placed with The English Electric Company Limited in the summer of 1925.

The initial installation comprises seven single-phase transformers, each of 3,333 KVA. capacity. These units form two 10,000-KVA. banks, with one unit as a spare. The H.V. windings are connected in Delta, and the L.V. windings in Star, for stepping down from 33,000 volts to 6,600 volts. A general view of the transformers in course of installation is shown in Fig. 1.

The Shell type of construction was chosen because it was considered that this design would result in a more robust and reliable transformer for the large size involved than the Core-type construction, and this decision was given complete approval by the Liverpool engineers.

The transformers are of the Oil-Immersed, Self-Cooled Type and are designed for Outdoor Service. A complete unit is shown in Fig. 2.

The coils are rectangular, and are wound in flat single sections with one turn per layer. The conductor consists of rectangular double-cotton covered wires, and insulation between the single-turn layers is provided by strips of hard insulating material. To the inside of the first turn and to the outside of the last turn of

FIG. 2. 3,333 KVA., SINGLE-PHASE OUTDOOR TRANSFORMER FOR A 10,000-KVA., 50-CYCLE, 33,000/6,600- VOLT, 3-PHASE BANK.

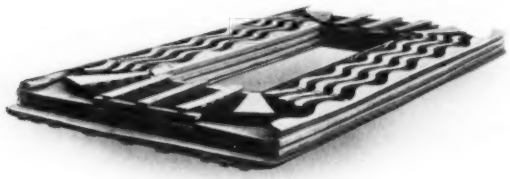


FIG. 3. ARRANGEMENT OF SPACERS.

each coil is taped a strip of insulation which maintains the necessary creepage distance between adjacent coils round the projecting edges of the washer that is placed between them.

A very important feature of the design of the windings and insulation is the adequate provision made for the circulation of oil, so that a very low temperature gradient between copper and oil is assured, and any danger of excessive local heating is eliminated.

There are 12 H.V. coils and 12 L.V. coils arranged in a sandwich manner in five groups, thus :—

LLL–HHHHHH–LLLLLL–HHHHHH–LLL

Adjacent coils are separated by a washer and oil duct, the latter being maintained by suitable spacers of insulation. Along the vertical portions of the coil these spacers are wave-shaped and so disposed that every wire is at the same time supported and also exposed to oil for the greater part of its length. At the corners of the coil specially formed spacers are used to deflect oil into the horizontal portions which are not in the direct line of oil flow. Fig. 3 shows very clearly the efficient arrangement of the spacers. The complete set of coils in a group is assembled with the various channels, angles and sheets of insulating material which provide the necessary insulation between H.V. and L.V. windings, and between the windings and the core, and the whole is bound together with strong webbing. Finally all the groups are banded tightly together so that the complete windings and insulation can be handled as a single unit.

Fig. 4 shows one such H.V. group, and Fig. 5 the complete set of windings for one transformer.

The insulating material used is suitable for forming into the various shapes required, and possesses the property of very readily absorbing oil, in which state it has the useful feature that its dielectric constant approximates to that of oil.

The amount of insulation between turns is determined not by the normal volts per turn, but by consideration of the line voltage and the service conditions. At the ends of the windings adjacent to the line this insulation is considerably reinforced to withstand the effect of surges, and the reinforcement is graded down through approximately 5 per cent. of the total number of turns to the normal insulation used in the body of the winding.

Coming now to the core, this consists, as usual, of thin laminations of very high quality silicon steel, one side of each lamination being coated with an insulating material that does not deteriorate with heating. The complete set of windings and insulation is placed in position in a massive structural steel bottom frame on which the core is built, and the laminations are stacked round the vertical coil sides with the corner joints carefully interleaved.

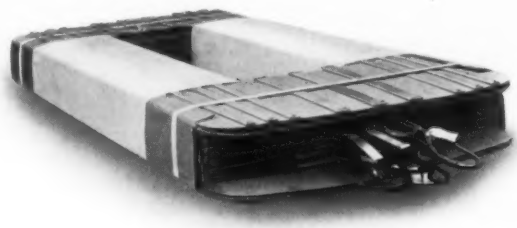


FIG. 4. A GROUP OF H.V. COILS.

The completely assembled core is clamped very tightly by means of strong tie bolts that unite the bottom frame with a similar one placed on top of the stack of laminations, wood packing being inserted between the frames and the core. The view in Fig. 6 shows the core partly assembled and gives a clear indication of the construction adopted.

Where the windings pass through the core they are effectively braced by the core itself, and the portions that project above and below the core are clamped by means of heavy steel plates placed parallel with the coil faces against the outside of the insulation, and tied together by strong tie bolts. The magnetic centres of the H.V. and L.V. windings are made as far as possible co-axial, with a view to minimising the vertical stresses produced under short-circuit conditions. To brace the windings against these vertical forces, T beams are placed through the opening in the windings and forced apart by large compression bolts; this arrangement also serves to relieve the core of the weight of the coils and insulation, and to transmit it to the lower frame.

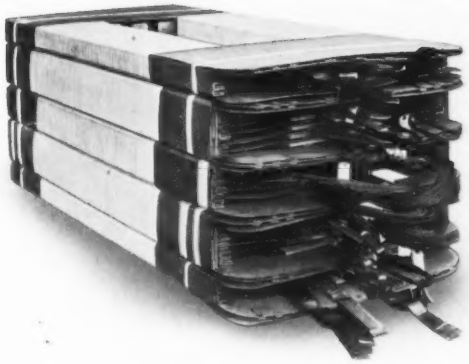


FIG. 5. COMPLETE SET OF WINDINGS FOR ONE TRANSFORMER.

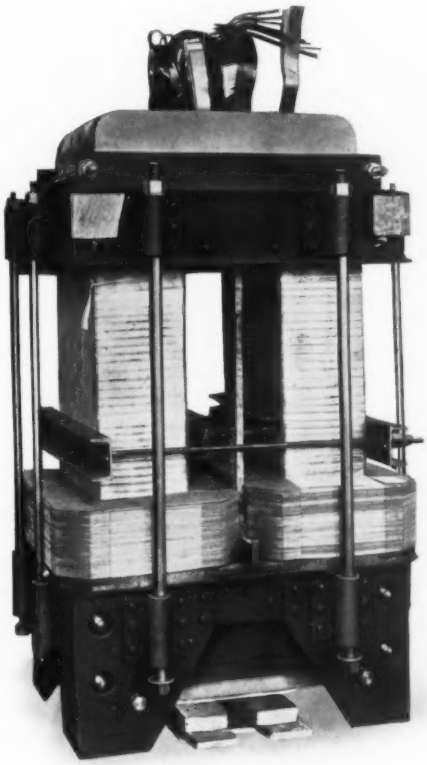


FIG. 6. WINDINGS IN POSITION IN FRAMES AND CORE PARTLY ASSEMBLED.

There are no tappings on the H.V. winding, but provision is made for series-parallel connections so that in case of necessity the transformer can be operated at 16,500 volts. The H.V. leads are made of copper rod encased in bakelised paper tubes. The L.V. tappings are located at the ends of the winding, and are connected to leads of flat copper bar. All leads are supported on a structure mounted on the upper main frame, and are so arranged that change of connection can easily be made through a manhole in the tank cover. A complete core with its windings and insulation is illustrated in Fig. 7 and the method of clamping the windings both vertically and horizontally is clearly shown.

Before being tested, the complete core with its windings was dried out in a vacuum tank into

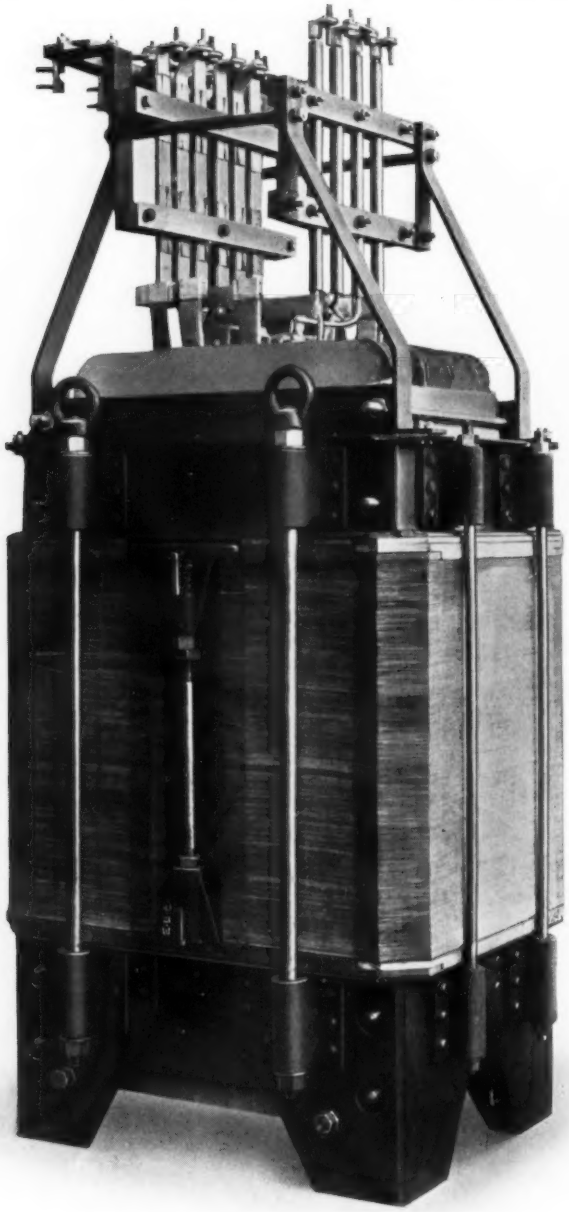


FIG. 7. COMPLETE CORE WITH WINDINGS OF 3,333 KVA. SINGLE-PHASE TRANSFORMER.

which oil was allowed to enter before the vacuum was broken, and by this means the winding and insulation became thoroughly dried and impregnated with oil which had been previously dried by a centrifugal oil purifier. Without undue delay the core with its windings and insulation was transferred to its own tank and immediately covered with oil.

The tank is of boiler plate, with welded seams, and the necessary cooling surface is provided by steel tubes welded into the tank side. As will be seen in Fig. 2 the tank is cylindrical; this shape gives great strength, and also by reason of the radial spacing of the tubes secures the maximum efficiency of the cooling surface. Round the top of the tank side is welded a strong rim of steel, to which the dome-shaped cast-iron cover is secured by means of stud-bolts that pass up through the steel rim into, but not completely through, the cover. A large number of bolts is used and an oil-tight joint is further assured by machining the surfaces of the cover and rim, and inserting a packing of oil-proof material between them. Massive lifting lugs are riveted to the tank side, and in order to prevent oil leakage along the rivet holes a thin plate of steel is welded inside the tank so as to enclose all the rivet heads; the design of the tank and lugs is such as to permit the complete transformer filled with oil to be lifted. The tank is supported on a structural steel base in which plain rollers are fitted.

When in service, the tank is completely filled with oil, and an auxiliary vessel provides the necessary free space into which the heated oil can expand. By this means the large surface of hot oil in the tank is protected from the atmosphere, thus preventing deterioration of the oil by oxidation, and entirely avoiding condensation of moisture on the underside of the tank cover.

The pipe that connects the main tank to the expansion vessel is of quite small diameter for the express purpose of keeping the oil in the latter undisturbed by the normal circulation taking place in the main tank under working conditions. The lowest part of the expansion vessel is arranged as a sump, fitted with a small cock, so that any moisture is collected and may be drawn off. As an additional precaution, since the transformers are for outdoor service, a calcium chloride breather is fitted in order to extract moisture from the air drawn into the tank when the oil contracts.

Great care was taken to provide suitable bracing between the transformer and its tank, so that no damage could possibly occur during transport.

On both H.V. and L.V. sides provision is made for the entry of single-core lead-covered cable by means of sealing bells, which are mounted in pockets on the tank side in such a way that they need not be disturbed when it is necessary to remove the main cover or lift the core and coils from the tank. The gland portion of the sealing bell is bolted to the main body with a vertical joint, so that the cable may be brought up from the floor or down from overhead, whichever is

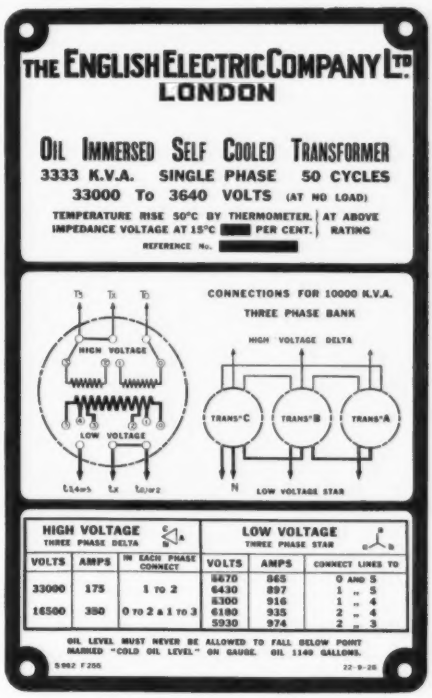

THE ENGLISH ELECTRIC COMPANY LTD
LONDON
OIL IMMERSED SELF COOLED TRANSFORMER
3333 K.V.A. SINGLE PHASE 50 CYCLES
33000 TO 3640 VOLTS (AT NO LOAD)
TEMPERATURE RISE 50°C BY THERMOMETER. AT ABOVE
IMPEDANCE VOLTAGE AT 15°C [redacted] PER CENT. RATING
REFERENCE No. [redacted]
CONNECTIONS FOR 10000 K.V.A.
THREE PHASE BANK
HIGH VOLTAGE DELTA
HIGH VOLTAGE
LOW VOLTAGE
TRANS°C
TRANS°B
TRANS°A
N
LOW VOLTAGE STAR
HIGH VOLTAGE THREE PHASE DELTA
LOW VOLTAGE THREE PHASE STAR
VOLTS | AMPS | IN EACH PHASE CONNECT | VOLTS | AMPS | CONNECT LINES TO
33000 | 175 | 1 TO 2 | 6670 | 865 | 0 AND 5
16500 | 350 | 0 TO 2 & 1 TO 3 | 6430 | 897 | 1 " 5
| | | 6300 | 916 | 1 " 4
| | | 6180 | 935 | 2 " 4
| | | 5930 | 974 | 2 " 3
OIL LEVEL MUST NEVER BE ALLOWED TO FALL BELOW POINT MARKED "COLD OIL LEVEL" ON GAUGE. OIL 1140 GALLONS.
5982 F255
22-9-28

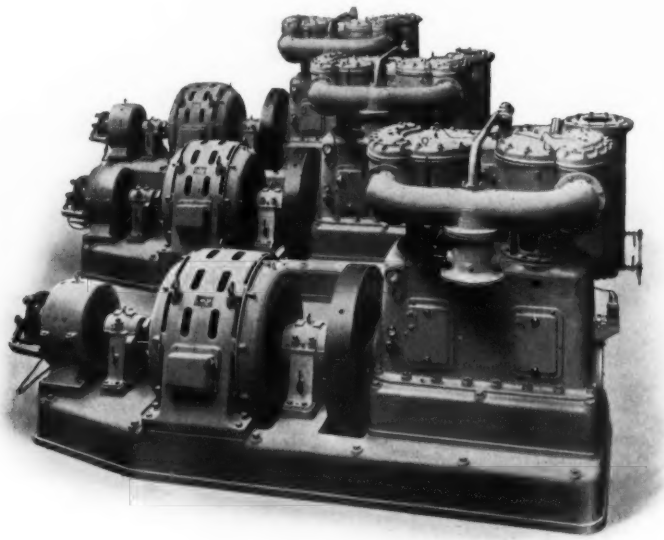
FIG. 8. DIAGRAM PLATE.

more convenient. All glands are interchangeable so that when one transformer has to be replaced by the spare unit, only the glands have to be unbolted and there is no necessity to disturb the cable joints. Three sealing bells are provided on both H.V. and L.V. sides, in order to avoid making external joints in the cables; in each case two sealing bells are connected inside the tank to one end of the winding, one of them being used for making the connections of the bank and the other for connecting to the incoming line. This arrangement is shown in Fig. 8 which is a reproduction of the diagram plate mounted on the side of each tank.

Each unit is provided with all the requisite accessories, including a draw-off valve, an oil gauge on the expansion vessel, and a thermometer; the latter is of the dial type and is mounted at a convenient height on the tank side, and connected by a capillary tube to a bulb located in the oil at the top of the main tank. The thermometer is equipped with electric contacts for operating an alarm in the event of the oil temperature reaching a predetermined value. The alarm contacts of all the transformers are connected to an indicator board in the switch room, and by means of a relay a Klaxon horn is sounded.

The weight of the core and coils is 15,200 lbs., and of the tank 12,000 lbs., while 1,150 gallons of oil are required. The complete transformer weighs 37,000 lbs., or 16·5 tons. The overall diameter of the tank is 97″, beyond which the cable sealing bells project on two sides, making the total floor space 130″×97″. The height to the top of the tank cover is 130″ and over the expansion vessel 153″.

In spite of the large size of these transformers, it was possible to dispatch them practically complete with oil, thus avoiding any drying out on site. The only assembly work which was required was the fitting of the expansion vessel, sealing bells and other external accessories.



The illustration shows three "English Electric" Asynchronous-synchronous, 3-phase Motors and "Reavell" compressors for a large industrial undertaking in India. Each Motor has an output of 235 H.P. at 300 R.P.M., and is designed for Unity Power Factor.

Transformers for Power Transmission.

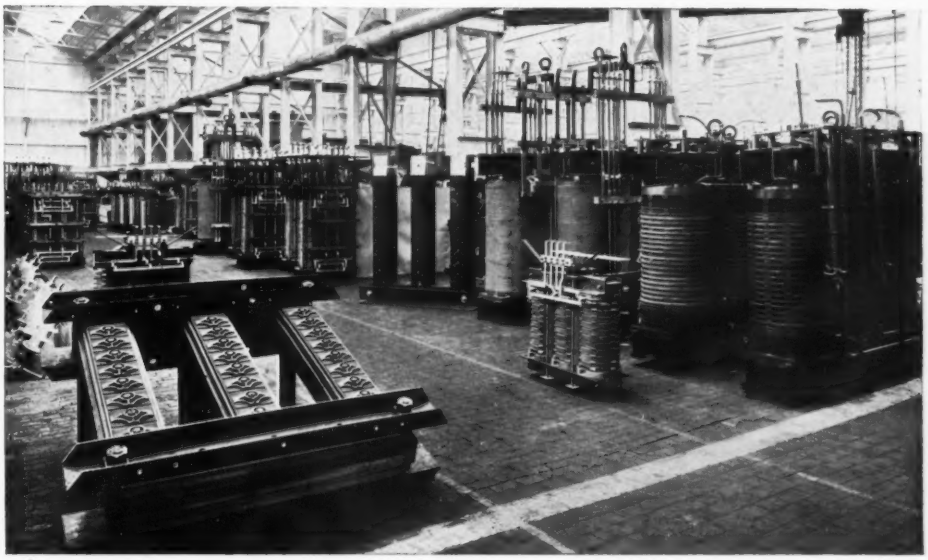


FIG. 1. A VIEW IN THE TRANSFORMER SHOPS, STAFFORD WORKS.

It is roughly forty years since the system of transmitting electric power by alternating currents was inaugurated.

The phenomenal development in the use of electricity is directly attributable to the static transformer, for it alone has rendered possible two of the most important factors in that development. Transformers have enabled the range of power transmission to be continually extended, and have made practicable the distribution of electricity over large and densely populated areas.

Water power has naturally attracted the closest attention as a prime mover wherever it exists, but, as a rule, it is far distant from the localities where electrical energy is required, and in order to transmit the power over these long distances with reasonable economy, transmission voltages have increased in remarkable steps. In 1894 the maximum voltage in use was 10,000, after which there was a steady increase to 80,000 volts in 1901. This remained a maximum until 1907, after which further increases took place until, in 1912, transmission was effected at 150,000 volts. Partly on account of the War, further advance became slower, but in 1920 transmission of power at 220,000 volts was an accomplished fact, and since then many hundreds of thousands of KVA. of 220,000 volt transformers have been installed, and are operating with complete satisfaction.

220,000 volts by no means represents the maximum pressure for which power transformers can be built, but a limit is at present imposed to the voltage for power transmission by problems of the insulation of the line. If it were otherwise possible and economical at once to increase the pressure of transmission to 500,000 volts, experienced transformer manufacturers would not hesitate to offer to build the necessary transformers.

The necessity for very high voltages of

transmission has not been felt in The British Isles because distances are comparatively small, but the development has been forced in countries such as America and Japan, where water power resources are very great, but are many miles from the industrial areas. Transmission pressures at home increased a few years ago to 33,000 volts, which was then the maximum pressure for which three-core cables could be constructed ; but a 50,000-volt three-core cable has now been laid, and single-core cables for 66,000 volts have been operating for some time. It is highly probable that overhead transmission at 66,000 volts will become quite common, but 110,000 volts is probably the maximum that will be considered economical in this country for many years to come.

The tremendous increase in the demand for electric power has not only resulted in a rapid increase in transmission voltages, but concurrently with this development transformers have been built for much larger outputs. In 1907 the maximum output of a single transformer was 10,000 KVA. From 1910 to 1916 14,000 KVA. was not exceeded, but in the latter year some 25,000-KVA. units were built. This figure was not passed until the present year, when a new record is being set by the manufacture of some 28,866-KVA., 220,000-volt units. The above figures refer to double-wound transformers, but auto-transformers of far greater size have been made, and at the present time a 66,667-KVA., 25-cycle unit of this kind is being built.

From what has been stated above, it may safely be claimed that we have reached the limits neither of voltage nor of output for power transformers, and undoubtedly surprising new records will be set up in the immediate future.

Although transformers for the highest voltages and outputs are not required for service in The British Isles, The English Electric Company have constructed many large and high-voltage units for the overseas markets, and they are fully prepared to undertake the manufacture of transformers to suit service conditions in any part of the world. Previous to 1911 transformers for 50,000-volt operation had not been built in England, but in that year there were constructed at the Stafford Works of The English Electric Company a number of 50,000-volt transformers, which have been in successful operation in New Zealand ever since. Fig. 2 shows one of these units, while Fig. 3 illustrates one of a number of 50,000-volt transformers

FIG. 2. 50,000-VOLT TRANSFORMER BUILT AT STAFFORD WORKS IN 1911.

FIG. 3. A RECENTLY BUILT 50,000-VOLT TRANSFORMER FOR OUTDOOR SERVICE.

recently completed for outdoor service in the same country.

True to its ever progressive policy, The English Electric Company determined some years ago to compete actively in the world market for large high-voltage transformers. In 1925 an order was received from the Tata Power Co., Bombay, for twelve single-phase units, each of 12,500 KVA. maximum rating, and for 110,000-volt operation, and a detailed description of these transformers appears elsewhere in this number of the Journal.

It may not be out of place here to refer to the importance of suitable manufacturing conditions in connection with the successful building of high-voltage electrical apparatus of this kind, since the best workmanship can be assured only in shops which are spacious, well-lighted and scrupulously clean. This Company is fortunate in possessing an ideal factory for the purpose in its Stafford Works, where important extensions were completed about twelve months ago, to cope with their increasing transformer business. Fig. 1 shows a typical view in the new shops, which are not only extremely light and commodious, but have the further advantage of being heated by filtered air, so that there is an entire absence of unnecessary dust.

After very careful consideration of all the problems involved in the manufacture of transformers for all kinds of service, The English Electric Company laid down a definite policy regarding the types that are most suitable for the various conditions which have to be met. In general, it may be stated that transformers for the smaller outputs, and even larger sizes if the voltage is very high, are built with Core type construction, particularly if they are three-phase units. Big transformers, and smaller sizes if the voltage is very low, and especially single-phase units, are made Shell type. The foregoing is a general statement, and it is difficult to make a hard and fast rule as to where the changeover from Core type to Shell type occurs, since within a certain range the choice depends on the detailed characteristics of the transformer under consideration.

The design of "English Electric" transformers is such that the highest performance is secured, while particular attention is paid to features which have a very important bearing on their reliability under service conditions. For example, in order to get the greatest service out of a transformer, the maximum temperature of any part of the winding must not exceed a certain value. In the past the general practice has been to guarantee the temperature rise as measured in the oil. This method by no means precludes the possibility of there being dangerous temperatures in the windings. In "English Electric" transformers the windings are designed so carefully, and with such ample provision for the circulation of oil, that a very low temperature gradient between copper and oil is assured, and any danger of excessive heating is eliminated.

Fig. 4 illustrates a low-voltage heavy-current coil for a concentric-wound Core-type Transformer in which these features of design are embodied. The coil is wound in several layers, each layer being exposed on at least one side to a series of axial oil ducts, which are formed by vertical spacers of insulation.

Fig. 6 shows the arrangement of spacers and oil ducts in the winding of a Shell-type Transformer, and clearly indicates the provision made for the effective cooling of every part of the coil. A description of the details of this type of winding is contained in another article on page 158 of this number of the Journal.

Another important feature in the design of "English Electric" transformers is that very efficient means are provided for the bracing of the windings and other parts to withstand the mechanical stresses produced on short circuit. This problem is assuming continually increasing importance in view of the tremendous amount of power that may be concentrated into a short circuit, now that power transmission systems are of such great capacity. Every "English Electric" transformer is designed to withstand a dead short circuit on the secondary terminals with full primary voltage maintained.

Fig. 4 illustrates how this feature is provided for in a spiral coil for a concentric-wound Core-type Transformer. At each end of each layer of the winding is placed a collar of very strong insulating material, shaped on the one end to the spiral form of the winding; at the extreme ends of the coil all these collars are flush and at right angles to the axis of the coil. This arrangement results in the conductor being supported throughout the circumference of the winding, which is therefore well braced in an axial direction to withstand the effects of a short circuit.

In order still further to minimise the effects of short-circuit stresses, the H.V. and L.V. windings are so placed with respect to each other that their magnetic centres are as nearly as possible coincident, and also the total effective heights of the columns of H.V. and L.V. windings are made equal.

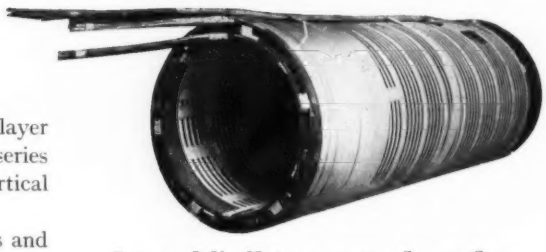


FIG. 4. L.V., HEAVY-CURRENT SPIRAL COIL.

An inherent feature of Shell-type Transformers is that a very robust construction can be made of the windings and insulation. Fig. 6 shows clearly how every wire is adequately supported by means of the special design of spacers. The coils are thoroughly packed on the inside so that a solid foundation is formed for the supporting beams which are placed through the opening in the windings and insulation, and which brace the windings against any vertical motion. As regards axial forces, the portions of the windings which are surrounded by the core are well supported by the latter; the projecting portions

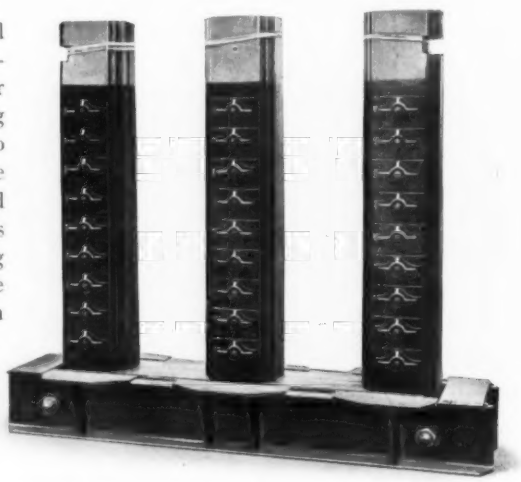


FIG. 5. TYPICAL 3-PHASE CORE WITHOUT TOP YOKE.

FIG. 6. ARRANGEMENT OF SPACERS IN WINDINGS OF SHELL-TYPE TRANSFORMER.

at the top and bottom of the core are braced by means of heavy steel plates placed parallel to the plane of the coils against the outside of the insulation, and tied together by strong tie bolts.

Further details of the design of " English Electric " Shell-type Transformers are given in the article to which reference has already been made.

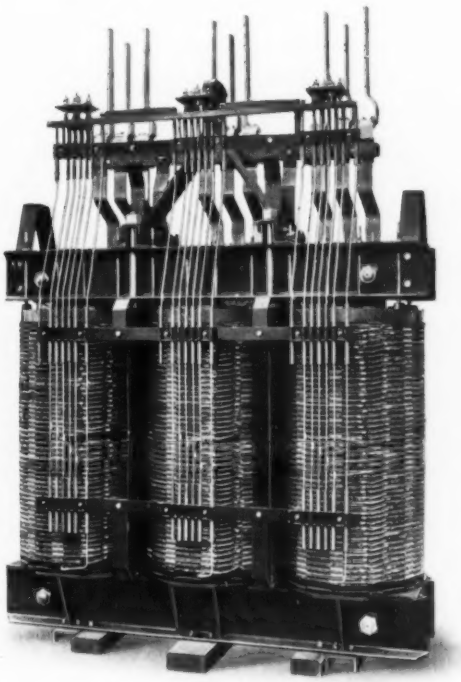


FIG. 7. H.T. SIDE OF THREE-PHASE UNIT FOR 2 200 KVA.

The core construction of " English Electric " Core-type Transformers is unique, since it breaks away from the conventional design in which vertical tie bolts are used between the upper and lower main frames. The core is built up with vertical limbs and horizontal yokes, the laminations of the yokes being interleaved with those of the limbs, and at the four corners of the core are rectangular notches into which are inserted heavy, insulated steel bolts, which thus key together the yoke and limb laminations. These bolts also serve to clamp structural steel frames to the yokes, and the complete core with its windings is lifted from the top frame without the use of vertical tie bolts. As will be seen by reference to Fig 5, which shows a typical core partly assembled, and Fig. 7 which illustrates a complete core and windings, this design gives a very simple but substantial structure.

In the conventional design of core the vertical tie bolts must be insulated from the windings, which becomes a difficult problem if the voltage of the winding is very high, but the " English Electric " design of core, by the elimination of the tie bolts, entirely removes this problem. This feature is also of great value on transformers with Sandwich-type windings ; Fig. 8 shows a transformer of this type, which is the one mainly used for Rotary Converter operation, where high reactance is required. The large amount of leakage flux which fringes out radially from the windings causes considerable loss and consequent heating in any metal parts in its field. In cores using vertical tie bolts this problem is a serious one, and to minimise the loss the bolts are made of phosphor bronze, but the elimination of the tie bolts in the " English Electric " construction entirely avoids the trouble.

For Rotary Converter operation, when high reactance is required in the transformer, The English Electric Company Limited decided to adopt the Sandwich-type of windings in preference to the use of magnetic shunts. The latter method of obtaining high reactance

suffers from the very serious drawback that the shunts become saturated at a certain load, beyond which any further increase in load is not accompanied by a corresponding increase in reactance. This feature has a serious effect on the operation of a Rotary Converter. Sandwich-wound Transformers, however, have the advantage that the characteristic of reactance is a straight line at all loads right up to short circuit. There are certain electrical and mechanical problems in the design of a Core-type Transformer with Sandwich Windings, but these have been solved very successfully in the special construction of core and L.V. windings employed in "English Electric" transformers of this type.

A very interesting and unique feature is incorporated in the design of the L.V. winding used on transformers with Sandwich-type windings. Normally the voltage is low and the current correspondingly high, and the usual design of the winding necessitates a large number of heavy soldered joints, which are not only an undesirable feature mechanically, but the joints increase the loss in the winding. This defect has been entirely overcome in a very interesting manner, which will now be described. Each L.V. group of coils is wound as a single continuous spiral of one or two layers, each turn being insulated from the next by means of washers or sectors of insulating material which are inserted during the winding of the coil, the sectors forming ducts for the circulation of oil between adjacent coils or pairs of coils. In the middle of each coil the wires forming the conductor are transposed in a special manner which reduces to a minimum the stray losses in the winding. This design has the advantage that the only connections to be made are at the ends of the groups, and it results in a very simple and neat winding having great mechanical strength. Windings of this special design are shown in Figs. 8, 9 and 10, which illustrate the features to which attention has been drawn.

Tubular tanks for self-cooled transformers are usually rectangular or square in plan. "English Electric" transformers of the larger sizes have circular or half-round ended tanks, the former being used for single-phase Shell-type Transformers, and the latter for Core-type Transformers. These shapes result in tanks having great strength and a more pleasing appearance than the older rectangular or square designs. The new construction has also the advantage of increased cooling efficiency due to the radial spacing of the tubes. On a square tank, for example, very little additional cooling is obtained by increasing the number of layers of tubes from three to four, whereas, with a circular tank, four or five layers of tubes may be used with practically proportional increase in cooling effect. Consequently, with "English Electric" designs a large self-cooled Transformer may be

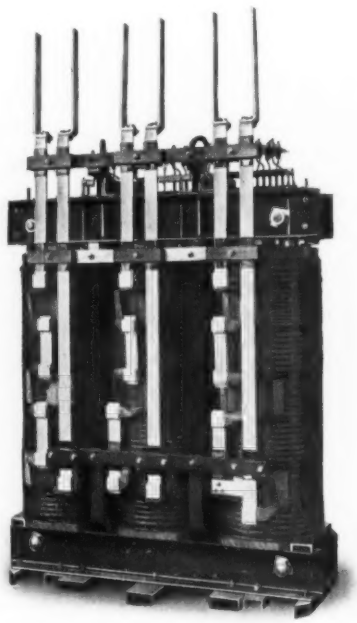


FIG. 8. A TYPICAL SANDWICH-WOUND CORE-TYPE TRANSFORMER.

built without using an unreasonably large tank. Fig. 11 shows a circular tank for a large Shell-type Transformer, and Fig. 12 is typical of tanks with half-round ends.

There is a growing tendency to use self-cooled transformers wherever possible, thus avoiding the extra complication of auxiliary apparatus for artificially cooling the oil. The largest self-cooled Transformer built up to the present is 15,000 KVA., except in the case of Auto-Transformers where a 36,000-KVA. unit has just been built.

The English Electric Company Limited is prepared to manufacture self-cooled Transformers for the largest outputs. To provide the necessary cooling surface for these large transformers, a number of external radiators are attached to the sides of the main tank. Each radiator consists of a number of elliptical tubes, welded at each end into headers which are attached to the tank by large elbows. The radiators are detached for despatch, thus greatly reducing the shipping dimensions.

For a number of years Outdoor Transformers for voltages up to the very highest have been in successful operation, and in connection with schemes at present going forward in The British Isles, there are signs that outdoor substations will become quite common. A transformer can be looked upon as being almost inherently suitable for outdoor service, since its vital parts are entirely protected in a metal case, and in order to make it entirely weatherproof it is only necessary to make a suitable design for the tank cover and the outlet terminals. Great attention has been paid to the details of "English Electric" Transformers for Outdoor Service. Fig. 3 shows a 50,000/11,500-volt, 50-cycle Outdoor-type unit for 1000 KVA.

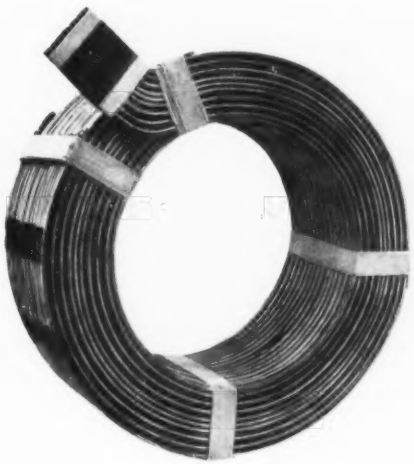


FIG. 9. L.V. SANDWICH COIL WITH SINGLE LAYER.

FIG. 10. L.V. SANDWICH COIL WITH TWO LAYERS.

It has been stated above that the policy of The English Electric Company Limited is to use the Shell type of construction for large transformers. There has always been considerable argument regarding the relative advantages and disadvantages of Core-type and Shell-type Transformers, and at the present time there are still two schools of thought on this subject. It is argued that Core-type construction is superior because the windings are circular. It can be shown, however, that under short-circuit conditions it is not the radial force that is liable to cause damage; hence, from this point of view, the Shell-type design with rectangular coils is not inferior to a circular-coil Core-type design.

The principal advantage of Shell-type transformers is that the windings are completely boxed in with insulation, which is built round with the core or the clamping gear. This design results in a very robust and solid construction which is very well able to withstand the forces caused by a short circuit.

The disposition of the windings in Shell-type Transformers is such that the oil ducts are in the vertical plane, which is an ideal condition to produce rapid circulation of oil, and consequently improved temperature conditions.

The size of tank required for a Core-type Transformer is determined by the clearance demanded for the voltage of the H.V. winding. If the voltage is very high the tank becomes very large, with a correspondingly excessive quantity of oil ; on the other hand, a Shell-type Transformer requires a tank only large enough to allow the core to pass with a very small clearance, and therefore this feature of the Shell-type design results in the best economy in tank and oil.

One of the greatest problems in the design of a high-voltage Core-type Transformer is how to support and insulate the H.V. leads effectively where they pass the top yoke and frame, and this difficulty is aggravated when a water-cooling coil is located in the upper part of the tank. The same problem does not enter into the Shell-type construction at all, because the portion of the winding from which leads are taken is entirely above the core and frames. The main insulation of the windings forms a very suitable foundation for the supports which hold the leads. The design also allows for the H.V. bushings being brought down close to the H.V. winding, thus reducing the height of tank required.

The special features of Shell-type Transformers are also very useful in cases where very heavy currents have to be handled, as for example, in large transformers for electric furnace work, and the leads can be taken straight up from the winding and out through the tank cover, which is clearly a much simpler construction than with the Core-type design.

At present the largest transformers manufactured in England are for service overseas, in which case shipping dimensions are of great importance. In this respect the Shell-type design has a big advantage over the Core-type design due to the inherent proportions of the former. A normal single-phase Shell-type unit has proportions of roughly 1 to 1 to 3, the latter being the height, whereas the corresponding dimensions of a Core-type Transformer are in the proportion of 1 to $2\frac{1}{2}$ to 6. Therefore a much larger transformer can be built within a certain loading gauge, by using the Shell type rather than the Core type of design. But the Shell-type construction has the further advantage that the transformer can be laid on its side for shipment, thus allowing a transformer of even

FIG. 11. TYPICAL CIRCULAR TANK FOR LARGE SHELL-TYPE TRANSFORMER.

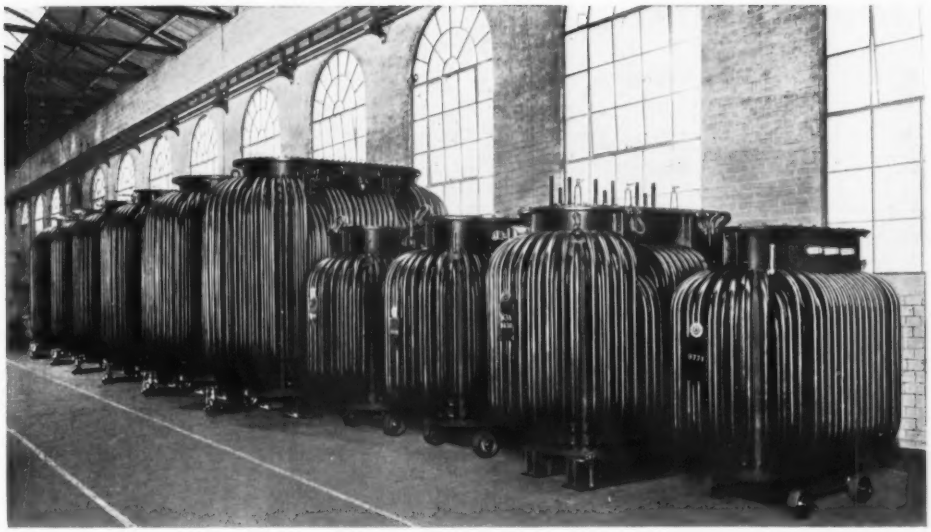


FIG. 12. GROUP OF TYPICAL TANKS WITH HALF-ROUND ENDS.

greater output to be built within the limits of the shipping dimensions ; this is an important argument in favour of Shell-type Transformers. Very big Core-type Transformers must be dismantled for shipment, but it is very undesirable to have to re-assemble on site a transformer for a very high voltage, probably more so than any other type of apparatus.

The English Electric Company Limited fully realise that a number of transformer users have a decided preference for Core-type design, and in these cases the Company is quite prepared to build the transformers with Core instead of Shell-type construction. An example of this is in the case of the transformers described in the article on page 145.

Electrical Equipment of New Plate Mill for The Consett Iron Company Limited.

[*Through the courtesy of Messrs. The Consett Iron Company Limited we are enabled to give the following description and illustrations of the complete electrical equipment for their new Plate Mill. The aggregate capacity of the main and auxiliary plant supplied by The English Electric Company Limited amounts to some 60,000 KW.*—EDITOR.]

One of the most important Steel Mill reconstructions that has taken place in recent years is that lately carried out by Messrs. The Consett Iron Company in connection with their Plate Mills. The site of the original Mills has been entirely cleared and new buildings and plant installed throughout.

The electrical installation is typical of many similar ones carried out by The English Electric Company Limited, and well illustrates the resources at their disposal for the correct determination of the power necessary for all classes of rolling mill work. Since 1906 a special department has been responsible for the installation of over 300,000 H.P. of main rolling mill drives.

The new plant consists of :—

40″ Two-high Reversing Slabbing Mill with 8′ 6″ rolls.

42″ Two-high Reversing Plate Mill with 9′ 6″ rolls.

32″ Three-high Light Plate Mill with 6′ 6″ rolls.

30″ Chequer Plate Mill with 6′ 6″ rolls.

The Slabbing Mill is designed for dealing with ingots up to 10 tons in weight and its product is passed forward in the form of slabs to both the Large Plate Mill and the Light Plate Mill,

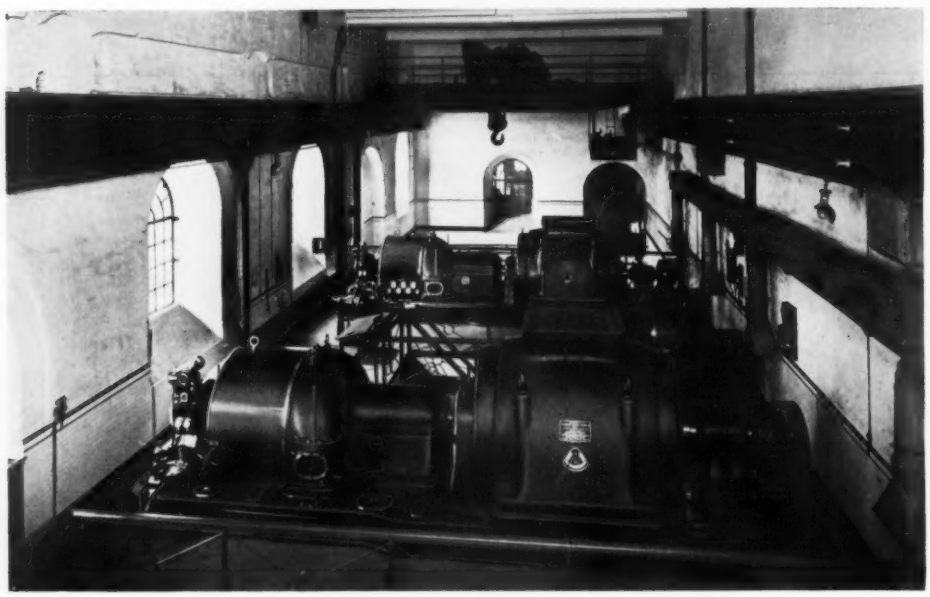


FIG. 1. TWO 3,000-KW., "ENGLISH ELECTRIC," 3-PHASE ALTERNATORS IN GENERATING STATION.

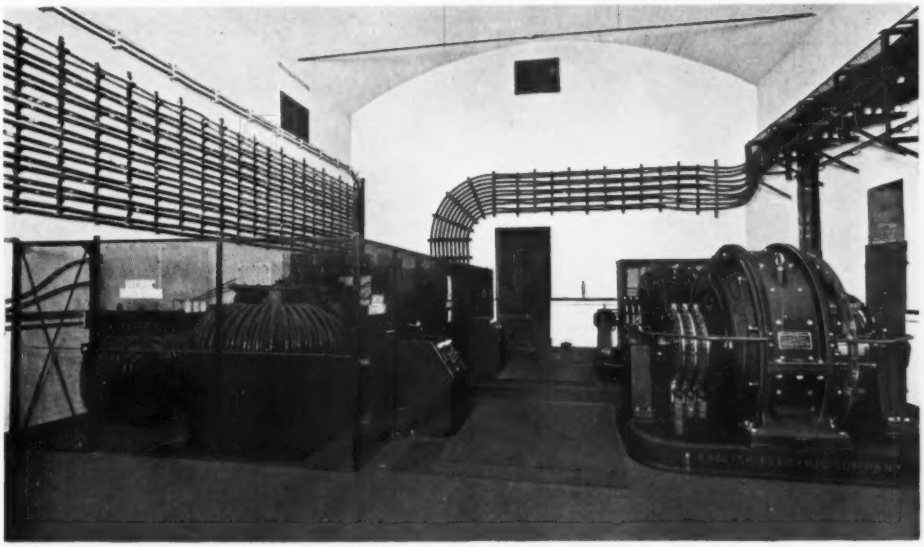


FIG. 2. ROTARY CONVERTER HOUSE WITH TWO 1,500-KW. "ENGLISH ELECTRIC" EQUIPMENTS.

the former rolling down to approximately $\frac{9}{16}$" thick as an average, and the latter to $\frac{7}{16}$" as an average. A certain proportion of the Light Plate Mill product passes on to the Chequer Mill.

In accordance with modern practice Electrical Drives have been used throughout, both for main machinery and auxiliary machinery, the latter including live rolls, manipulators, screw-downs, shears, skids, cranes, etc.

For the supply of the necessary power The Consett Iron Company have put down a Generating Station equipped with two 3,000 KW. 3-phase turbo-alternators and a 1,000 KW., D.C. geared turbo-generator, and have, in addition, installed three 1,500 KW. rotary converter sets for supplying direct current for auxiliary power. As an additional source of power a parallel supply is taken from The Newcastle-upon-Tyne Electric Supply Co., which can be either utilised as 3-phase power or converted through the above-mentioned rotary converters to direct current.

A view of the Power Station showing the two turbo-alternators is given in Fig. 1. Each of the "English Electric" alternators is designed for an output of 3,000 KW., 3-phase, 40 cycles at 3,000/3,300 volts. The 1,000 KW., D.C. geared set consists of an "English Electric" turbine running at 3,000 R.P.M. driving a 1,000 KW., 500/550-volt D.C. generator at 600 R.P.M.

The Rotary Converter House, which contains two 1,500 KW. rotaries, is shown in Fig. 2. The incoming supply voltage to the transformers is 3,000 volts and the D.C. output is at 480 525 volts, the machines being level compound wound within this voltage range.

The third rotary converter, which is of similar power, is housed in the same building as the main flywheel equaliser sets, and is shunt wound. This difference in windings was decided upon as the latter machine is much closer to the auxiliary machines which it is supplying, and the falling characteristic of the shunt-wound machine corresponds to the drop in volts in the longer leads from the level compound-wound machines. All three machines embody the latest practice in rotary converter

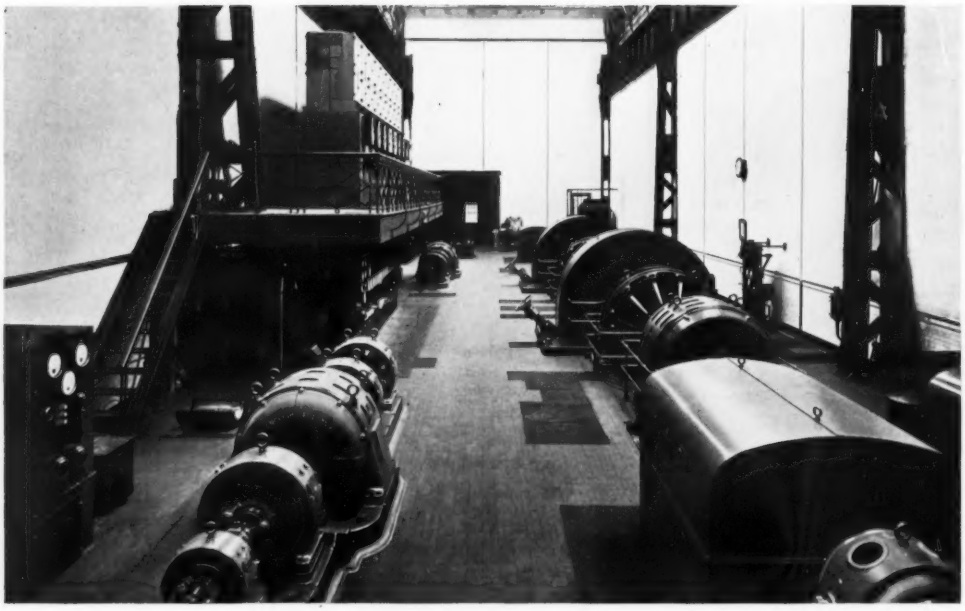


FIG. 3. MACHINE ROOM FOR LARGE REVERSING MOTORS. LOOKING TOWARDS SLABBING MILL MOTOR ANNEXE.

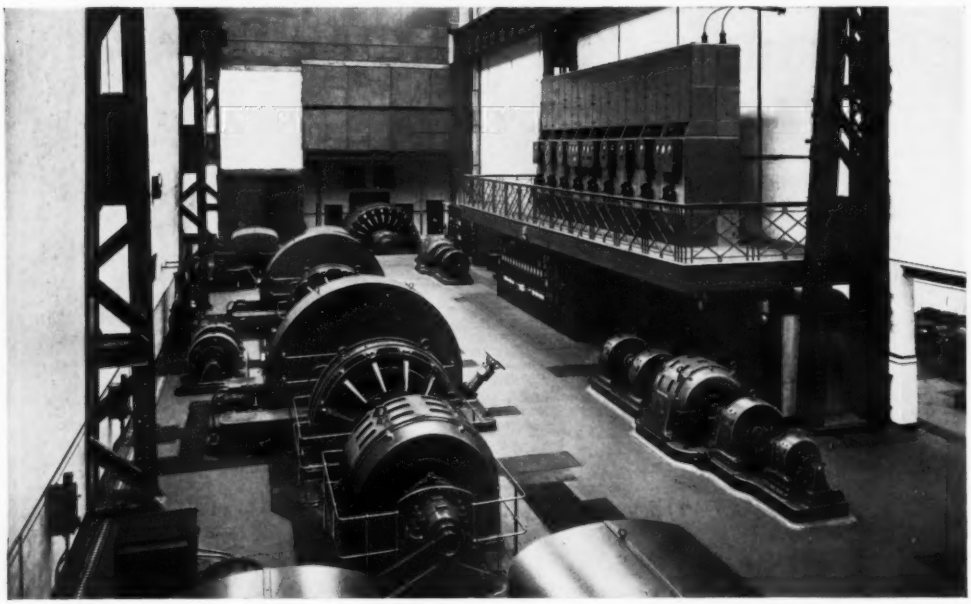


FIG. 4. MACHINE ROOM FOR LARGE REVERSING MOTORS. LOOKING TOWARDS PLATE MILL MOTOR.

design, including roller bearings and "tap" starting.

The 40" Slabbing Mill and the 42" Plate Mill are both reversing two-high Mills driven by reversing motors which take their power from two flywheel equaliser sets. The main building for the flywheel sets and the reversing motors is illustrated in Figs. 3 & 4, the former looking towards the Slabbing Mill motor, which is housed in the annexe at the end of the building, and the latter looking towards the Large Plate Mill motor which is seen in the distance.

Referring to Fig. 4, the incoming 3,000-volt switchgear appears on the platform on the right, and below the platform is a D.C. distribution board. On the left are the two flywheel sets mounted in line and coupled together by means of a flexible coupling. The two exciter sets appear as partly under the switchboard gallery, whilst in the foreground is one of the automatic slip regulators which maintain the input to the motors of the flywheel sets approximately constant by varying the speed of the set. On the extreme left in the centre of the flywheel sets can be seen a small motor generator barring set, the duty of which is described fully later on.

The reversing motors for both the Slabbing Mill and the Large Plate Mill are duplicate machines of the double-armature type and are illustrated in Figs. 5 and 6. Each set is designed for a peak power of 14,000 H.P. at 50 R.P.M. and has a speed range of 0/50 R.P.M. at constant torque and from 50/100 R.P.M. at approximately constant horse-power. The generally massive construction of these machines is well illustrated by the photographs. The frames, armature spiders, commutator hubs and coupling pieces between the two armatures are all of cast steel, and the bearings and bedplates are of particularly heavy construction in cast iron.

Some of the leading particulars of these machines are of interest :—

Weight of each complete motor	180	tons.
Weight of two armatures ..	80	,,
Diameter of shaft extension ..	26	inches
Overall length	324	inches
Overall width	211	,,

The two halves of each machine are exact duplicates, and the shaft is extended at the remote end so that should any accident happen to the shaft end at present being used for driving, the armatures can be interchanged. The bearings are ring lubricated, but in addition a motor-driven pump provides flood lubrication, if desired. Forced ventilation is employed on the machines, filtered air being blown by motor-driven fans through ducts in the foundations up into the centre portion of the machines whence it is distributed through the armature and frames and finally blown out over the commutators. Following usual "English Electric" practice, no through shaft is employed. Each armature is fitted with its own stub shaft and the connection between the two armatures is formed by a steel ring which registers on coned extensions of the armature spiders ; suitable fitted keys take the drive between the two machines, so relieving the coupling bolts from any shear strain.

The direct-current supply for each of the reversing motors is provided from a flywheel equaliser set consisting of a 3-phase induction motor of 3,000 H.P. driving two variable-voltage generators, between which is mounted a built-up cast steel flywheel 48 tons in weight, and 11 ft. 3 ins. in diameter. The flywheel sets are duplicates of one another and are arranged in line so that they can be coupled together for further equalisation of the load, the coupling between the two machines being of a "flexible" type, made by The Wellman Bibby Co., designed to transmit momentary peak loads up to approximately 14,000 H.P.

The arrangement of the flywheel set is clearly shown from the illustration, Fig. 7. The flywheel in the centre has its shaft extended in both directions and fitted with solid couplings to which the armatures of the generators are rigidly bolted. An outer bearing supports the other end of the armature and the driving motor rotor is again solidly coupled to the armature

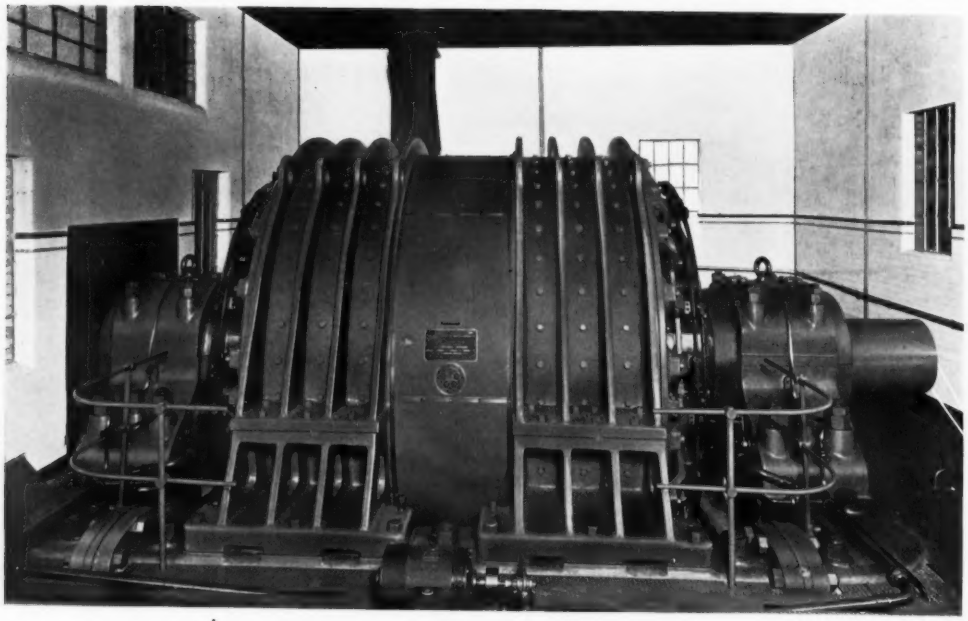


FIG. 5. 14,000-H.P. REVERSING MOTOR FOR SLABBING MILL.

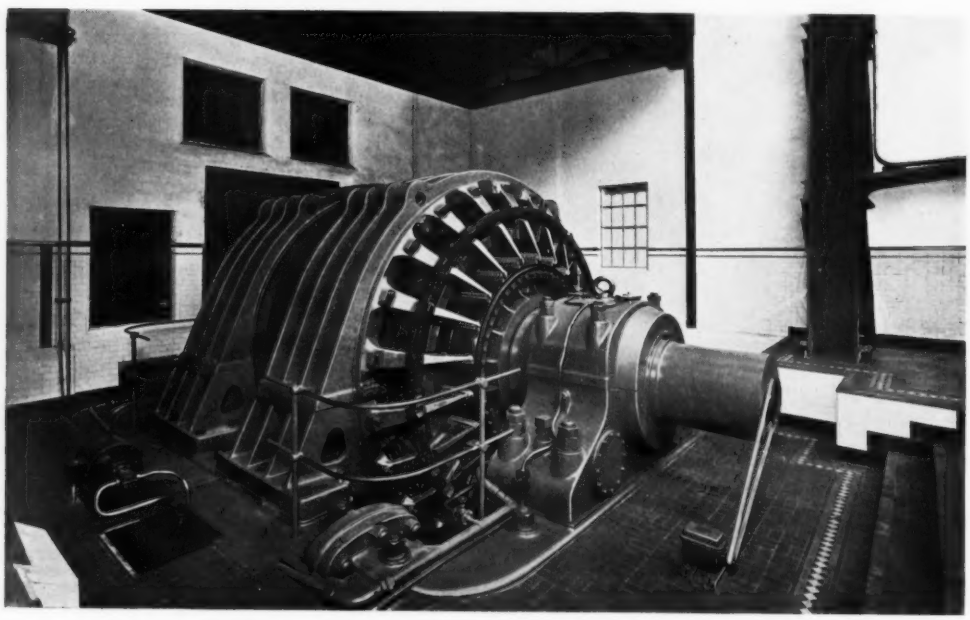


FIG. 6. 14,000-H.P. REVERSING MOTOR FOR LARGE PLATE MILL.

of the generator with an outboard bearing for the slipring end. Each set is approximately 40 ft. long, but the use of solid couplings and five bearings has not introduced any bearing difficulties whatever. The flywheel bearings are pressure lubricated, the pumps working up to about 150 lbs. per square inch, and under these conditions the flywheels are floating on a film of oil. This has the great advantage that it is possible to start up the set with something less than half load on the motor, and the friction losses of the flywheel are practically negligible.

A double system of lubrication is employed, pumps belted from the flywheel shaft being in use when the set is running, while motor-driven standby pumps are used during the starting and shutting down periods and as a standby in the event of accident to any of the belt-driven pumps.

The motor driving each of the flywheel sets is of the 3-phase induction type, wound for an incoming supply pressure of 3,000/3,300 volts, 40 cycles, and drives the set at a synchronous speed of 600 R.P.M. The working speed range is between 590 and 470 R.P.M. The generators in series supply the mill motors, and as they are subject to the peak demands are of specially strong mechanical design, cast steel being employed for the frames, armature spiders and commutator centres.

In order to give quiet running, the flywheels are entirely encased in sheet steel covers. A band brake, operated by the hand-wheel seen on the near side of the cover, is used for bringing the set to rest.

The control of the direction and speed of the reversing motors is brought about in practically all modern equipments by the control of the fields of the exciter machines which provide power for the fields respectively of the mill motors themselves, and of the generators supplying them with power. This method simplifies the control gear as it removes the operating mechanism from the main fields to that of the exciter fields.

In Fig. 8 appears one of the exciter sets, which is usually composed of four machines, but in the present instance consists of five machines owing to the fact that the driving motor—the large machine in the centre—is of the synchronous type for which D.C. excitation is required.

Reading from right to left the machines are as follows :—

Bucking exciter for mill motor field, main

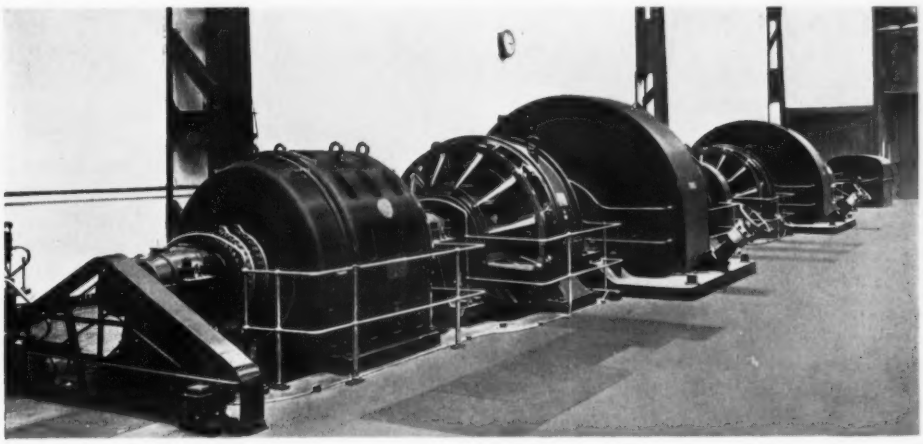


FIG. 7. THE TWO FLYWHEEL EQUALISER SETS FOR THE REVERSING MOTORS.

exciter for mill motor field and for excitation of the other exciter machines, synchronous driving motor for power factor correction, exciter for fields of variable-voltage generators, exciter for synchronous motor.

Consideration of the design of the exciter sets will show that they provide the greatest possible factor of safety to the main plant if any particular exciter machine fails. Should the bucking exciter fail when in operation, the field of the mill motor is automatically brought back to full strength, preventing any risk of over-speed. If the main mill motor exciter fails it automatically takes the field off the exciter of the variable-voltage generator, so bringing everything to rest. Similarly, any failure of the variable-voltage generator exciter merely has the effect of bringing the mill motor to rest, as it takes all field off the generators.

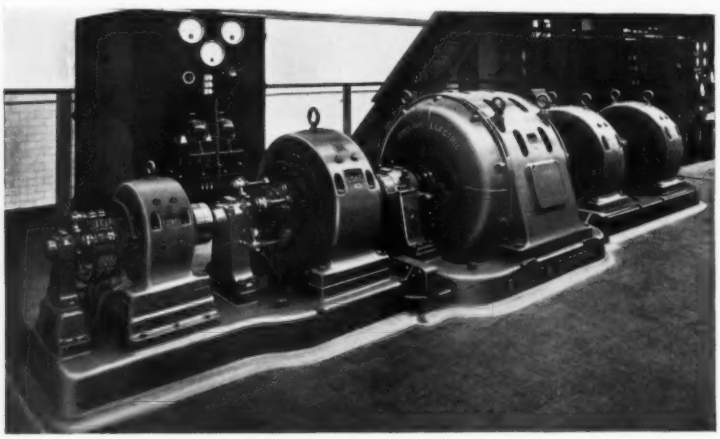


FIG. 8. EXCITER SET FOR REVERSING MOTOR AND FLYWHEEL SET.

The employment of synchronous motors for driving the exciter sets was decided upon with a view to bringing approximately to unity the power factor of the complete plant, including the two flywheel sets, the light plate mill motor and chequer mill motor. Each machine can provide 800 wattless KVA., thus giving a total for the two of 1,600 KVA.

The older method of using quick excitation resistances for reducing the time constant of the mill motors and variable-voltage generators, and thus ensuring very rapid acceleration, has been discarded in favour of special compound windings on the exciters in accordance with patented designs of The English Electric Company; these windings act in a similar manner and have the great advantage that the loss of energy in the quick excitation resistances is avoided, with the result that the size of the motor driving the exciter set is reduced by about one-half, and in the present instance only approximately 110 H.P. is required for the purpose.

The high-tension incoming mains from the Power Station are brought to the stonework-cell type board shown in Fig. 9. The busbars are in duplicate so that the alternative source of supply can be utilised by means of throw-over switches. The design follows the usual lines for this type of switchgear. The operating handles of the oil circuit-breakers are of the "loose-handle" type and are mounted on the front of the board and connected by rods and levers to the oil breakers which are enclosed in stonework cells at the back of the board. Adjustable time-limit devices are fitted to the outgoing circuits and the usual indicating and integrating instruments can be seen mounted in sheet metal cases on the front of the board. The upper portion of the cellwork contains the busbars.

Below the switchboard gallery is a D.C. distribution board, Fig. 10, which supplies the small motors for driving pumps, fans, etc.

There are two incoming panels on which are seen main circuit-breakers controlling the two independent sources of supply; the panel on the extreme left and a similar panel on the right carry instruments indicating the various field currents flowing at any moment and, in addition, the minimum relays and over-load relays which provide protection to the plant. On the extreme right is a testing panel fitted with recording instruments to enable test readings to be taken on the operation of any equipment. Throw-over switches allow the instruments to be inserted in either the Slabbing Mill motor equipment or the Plate Mill equipment. This board is of the usual enamelled slate panel type.

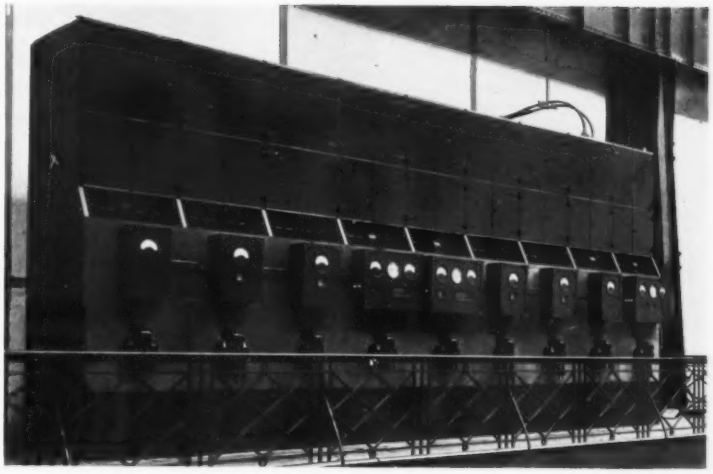


FIG. 9. H.T. CELLULAR SWITCHBOARD FOR A.C. SUPPLY TO FLYWHEEL SETS.

Following the latest "English Electric" practice, the main controllers for the reversing motors, which work by regulating the exciter fields, are removed from the control platforms in the Mill where they are subject to metallic dust and bad atmospheric conditions generally, and placed in the Flywheel House reasonably adjacent to the exciter sets; one of the controllers is illustrated in Fig. 11. The only connection between the control lever on the Mill platform and the controller itself is a single play-pipe filled with alcohol and water solution. This play-pipe ends in a diaphragm mounted in the pedestal of the control lever at the one end and in a similar diaphragm attached to a rocking valve lever at the controller end. A movement of the control lever

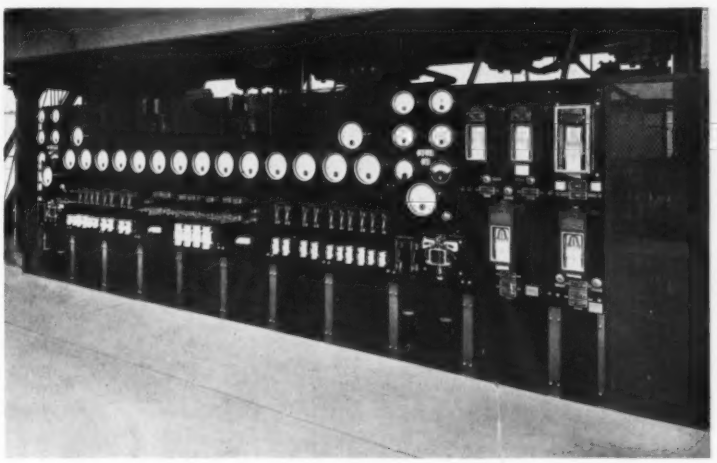


FIG. 10. D.C. SWITCHBOARD FOR DISTRIBUTION TO D.C. AUXILIARIES.

displaces the diaphragm from the central neutral position and an entirely synchronous movement takes place on the diaphragm at the controller. Any movement of this nature opens a valve which admits pressure oil to an operating servo-motor, which in turn gives a setting of the controller arm corresponding to the position of the control lever. From the illustration, the position of the diaphragm and the general design of the oil servo-motor and valve mechanism are clearly shown. On the right is seen an air vessel through which the pressure oil passes on its way to the servo-motor. This provides a damping action and at the same time a reserve of power for bringing the controller to the "off" position in the event of the oil supply failing. The tank on the left acts as a supply tank for the oil pump and the operating oil returns to it after circulating through the servo-motor system. Under normal working conditions the oil pump is driven by belt from the flywheel set, but a spare motor-driven pump is provided to act as a standby. By making use of pressure oil for operating the controller, the physical effort required from the driver of the mill is very much reduced and fatigue largely eliminated.

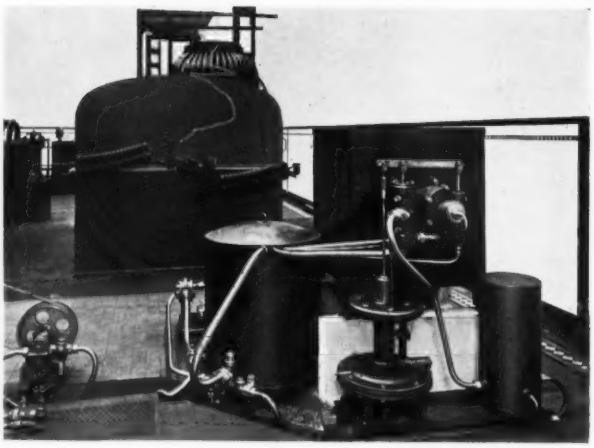


FIG. 11. CONTROLLER FOR ONE OF THE 14,000 H.P. REVERSING MOTORS.

The operating lever mentioned as being mounted on the control platform in the Mill is clearly seen in Fig. 12, to the right of the instrument desk. The diaphragm is fixed in the bottom of the pedestal and operated from the lever. An oil pressure gauge mounted alongside indicates to the driver that the oil system is working correctly.

FIG. 12. CONTROL LEVER AND DESK OVERLOOKING MILL.

The Mill driver when working the control lever stands adjacent to the instrument desk so that the various instruments are immediately beneath his eye and give him information as to the current flowing to the mill motor, the speed of the mill motor and the speed of the flywheel set. A red lamp also gives him warning if the speed of the flywheel set has been reduced below the lower working limit, while "stop" and "start" push buttons enable him to close a relay circuit which opens or closes the field of the main exciter, so that the plant can be

FIG. 13. TUNNEL FOR CONNECTIONS UNDER MACHINE ROOM.

put into commission or stopped at will.

The various master controllers seen in the background operate contactor gear which controls the screw-down motors, manipulator gears and live rolls.

Behind the controller in Fig. 11 is one of the automatic slip regulators on which can be seen the spring balancing device for the moving blades. These blades rotate about a spindle and enter a soda solution contained in the tanks. The position of the blades in the tanks determines the resistance in the rotor circuit of the motor driving the flywheel set and consequently regulates its speed. The extent to which the blades are immersed is determined by a torque motor which drives on to the blade spindle through a chain, and the power of the torque motor is obtained from the input current to the flywheel motor. So long as the current to this motor remains at the desired value, any tendency to rotate on the part of the torque motor is counterbalanced by the weight of the blades. With increasing current the torque motor overcomes the counterbalancing force and raises the blades in the liquid, inserting resistance, which produces a fall in speed and thus liberates energy from the flywheel. With a reduced current the reverse action takes place and the weight of the blades causes them to enter further into the liquid, reducing the resistance, and thus speeding up the flywheel set again.

Earlier in the article the Barring Set was referred to. This appears at the back of the flywheel set shown in Fig. 4. It was considered desirable to have available, means for obtaining slow movement on either of the main reversing motors or on the flywheel sets. The provision of a Barring Equipment on each machine would have been somewhat cumbersome, so the difficulty was overcome by the introduction of a heavy-current low-voltage motor-generator set; by this means current can be passed through the armature of either of the mill motors, or of any of the variable-voltage generators, of sufficient magnitude to give half full-load torque with the fields of the machines normally excited, and a speed which corresponds to a few revolutions per minute. The Barring Set is brought into use by plugging it to the main bars which feed the particular machine to be rotated.

The heavy current of the order of 12,000 amperes cut-out value flowing between the generators of the flywheel sets and the mill motors necessitates the use of copper strip connections, and to accommodate these and the large number of field connections which pass between the various machines, the controllers and the switchboard, an underground tunnel, Fig. 13, was constructed from end to end of the Motor House, *i.e.*, reaching from the Slabbing Mill motor at one end

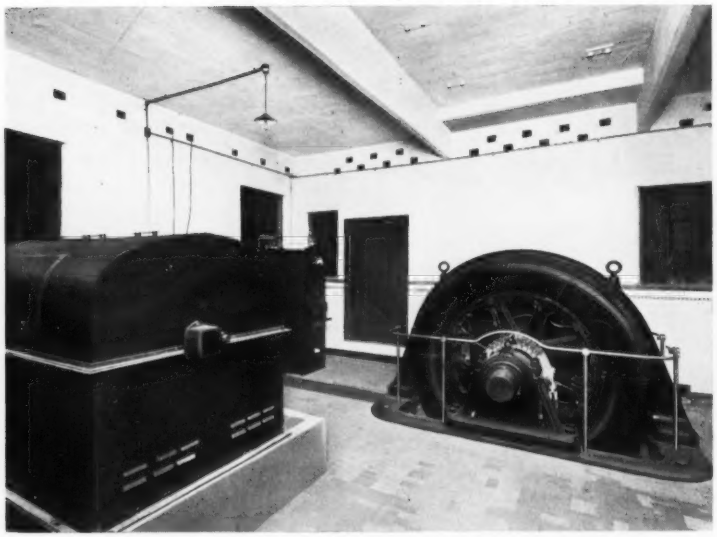


FIG. 14. MOTOR HOUSE FOR 1,500 H.P. CHEQUER PLATE MILL MOTOR.

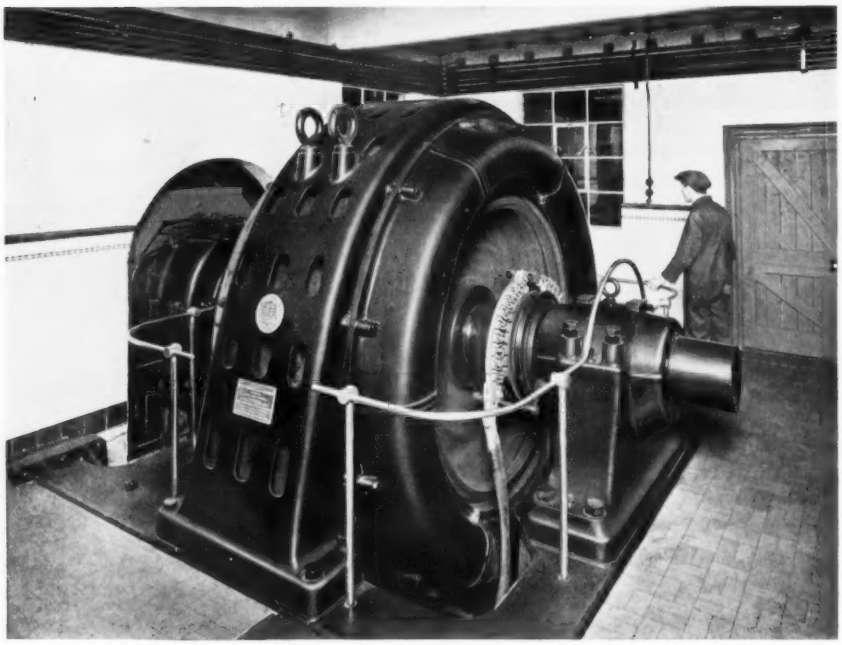


FIG. 15. 2,500 H.P., 240 R.P.M. INDUCTION MOTOR DRIVING LIGHT PLATE MILL.

to the Large Plate Mill motor at the other.

In this tunnel was concentrated the whole of the wiring; the high-tension three-core cable leading in from the Power House appears half-way up on the right-hand wall, whilst the heavy bare copper strip connections for the main current are seen mounted on porcelain insulators on both sides. The field connections are supported on insulators carried on brackets from the roof.

The two flywheel sets are placed approximately half-way between the two motors, and where the connections from the generators enter the tunnel the bars are arranged with a system of links whereby interchangeability of any generator with any motor is possible. This will ensure continuity of production of either Mill in the event of an accident to any one of the generators. The change-over of the main connections is accompanied by a corresponding change-over of the various field connections, and a switchboard arranged behind the D.C. switchboard carries the necessary apparatus for this purpose.

The Light Plate Mill is of the three-high "Lauth" type in which the top and bottom rolls are power driven and the intermediate roll is brought into contact alternatively with the top or bottom roll, taking its rotation by friction from the roll with which it is in contact. With such a mill the rotation is always in one direction, so that a continuous-running motor can be employed.

In the present instance a 3-phase induction motor of 2,500 H.P. running at 240 R.P.M. provides the necessary power, and the machine is illustrated in Fig. 15.

Interposed between the motor and the mill is a flywheel 38 tons in weight and 16 ft. in diameter; a reduction gear combined with the pinions in the pinion housing reduces the motor speed to the 60 R.P.M. of the mill.

The control pillar for the motor is of standard "truck" type, and for starting purposes a liquid starter is employed; in conjunction with the latter there is a permanent

FIG. 16. 100 H.P. MILL MOTOR DRIVING PLATE MANGLE.

metallic slip resistance designed for a drop in speed of 10 per cent. from no-load to full-load, so that the stored energy of the flywheel may be utilised on the heavy passes.

The Chequer Plate Mill consists of a single two-high stand running continuously in one direction, one pass sufficing to put the chequering on the plate. This Mill is driven by a 3-phase motor designed to take peaks up to approximately 1,500 H.P. It is of the simple induction type, runs at 240 R.P.M. and is geared down to the mill, which has a speed of 35 R.P.M.

Overhung on each side of the pinion of the reduction gear is a flywheel 8 ft. 6 in. diameter, weighing 11¼ tons, and the energy of these two wheels is brought into play by the introduction of a metallic slip resistance in the rotor of the induction motor.

A general view of the Motor House appears in Fig. 14, which shows the disposition of the high-tension control pillar and the liquid starter. Practically the same arrangement of

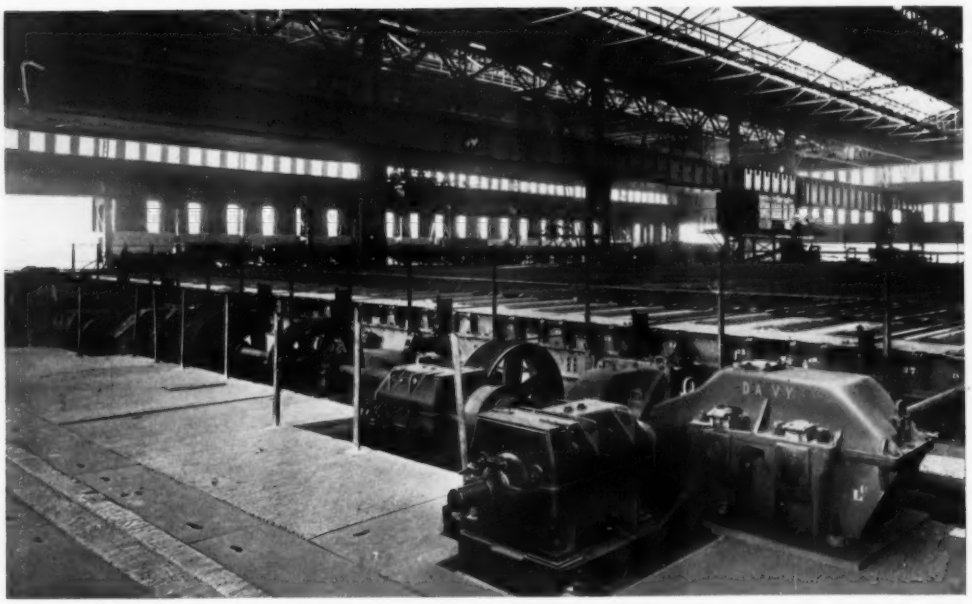


FIG. 17. GENERAL VIEW OF COOLING BANK, SHOWING 40 H.P. & 60 H.P. MILL MOTORS FOR LIVE ROLLER AND SKID GEAR.

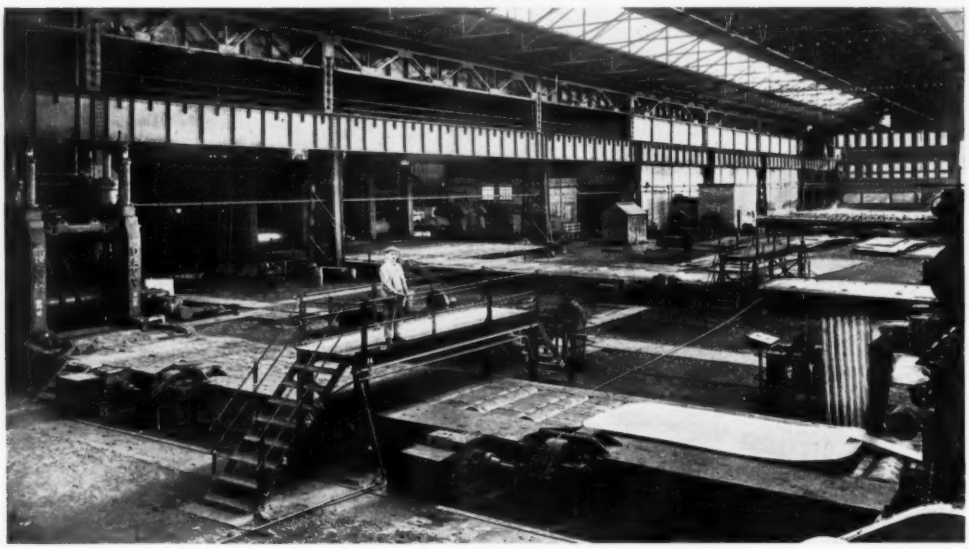


FIG. 18. GENERAL VIEW OF THE LAY-OUT OF THE MILL.

House is adopted for the Light Plate Mill Drive mentioned above.

The advantages of direct-current motors for such duties as live rolls, screw-down gear, manipulators, mangles, cranes, etc., led to the decision to adopt such machines throughout the whole plant as well as for similar duties in the Angle and Bar Mills, which have also been reorganised.

The class of motor adopted is that known as the " mill type," Class MM, which is specially designed for the very heavy duty entailed in such classes of work as live rolls, screw-downs, etc. The general appearance of these machines is well illustrated in Fig. 19, where four of them appear in connection with the Slabbing Mill. The two mounted below ground level operate the manipulators and are each of 100 H.P. at 550 R.P.M. The one on the left, which is 60 H.P., controls the tilting device, and one of the two screw-down motors of 60 H.P. is seen mounted up on the top of the mill housing. As will be seen, the motors are of very compact and strong design, the frames being of cast steel split on the centre line ; the machines are built so that in the event of an accident to the driving shaft end, the whole machine can be reversed end for end, thus bringing into action the shaft extension at the other end. The insulation used is fire-proof and every precaution is taken to prevent the lodgment of dust in any position where it may cause trouble.

In Fig. 16 is shown a motor of this class, of 100 H.P., driving one of the plate mangling machines, and this differs from the motors previously referred to in that, in order to prevent excessive speed when no plate is in the mangles, a shunt winding is fitted as well as a series winding.

A view of the cooling banks appears in Fig. 17 and in the foreground are seen the live roller and skid gear motors, the former of 40 H.P. and the latter of 60 H.P.

Some idea of the mill lay-out is obtained from Fig. 18. In the background on the left appears the building which contains the flywheel sets and reversing motors. The two stands of the 42″ Reversing Plate Mill can be seen adjacent to this building, and in the foreground on the left is the chequer mill which is in line with the three-high Plate Mill. On the right-hand side is part of the mangle for the Light Plate Mill. The operating motors for the run-out and live rolls are clearly visible.

The extent to which power is used for auxiliary machinery is shown by the fact that over 280 motors have been supplied in conjunction with this equipment.

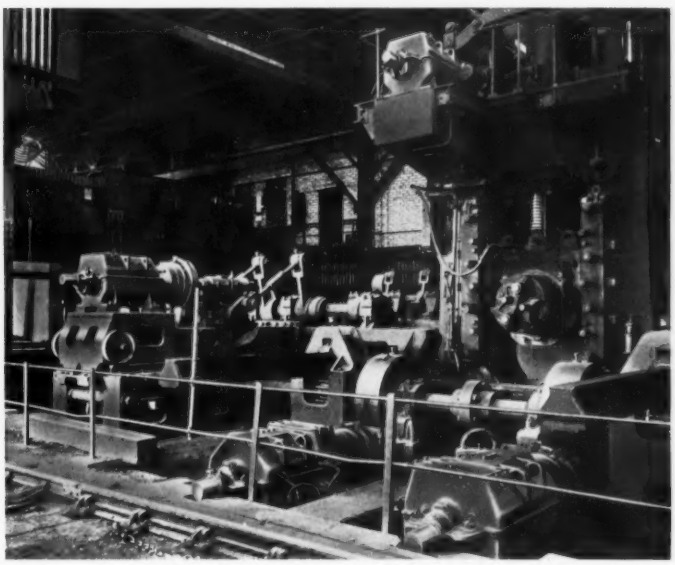


FIG. 19. 100 H.P. & 60 H.P. MILL MOTORS DRIVING SLABBING MILL AUXILIARY GEAR.

Multiple-Unit Operation of Tramways and Light Railways.

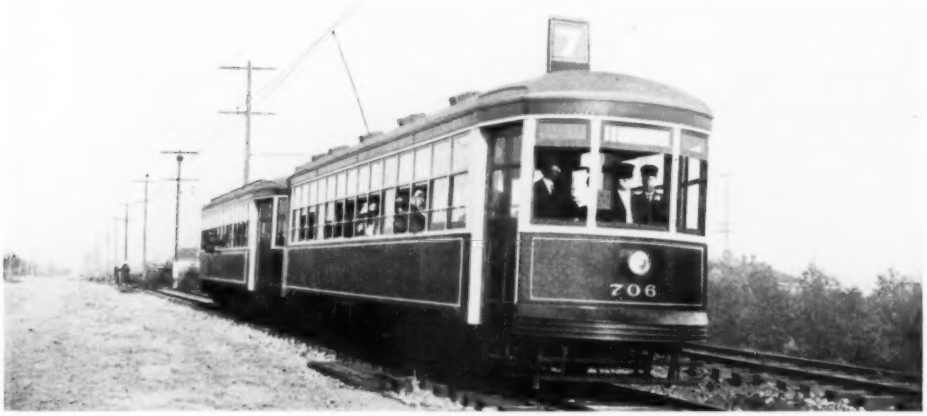


FIG. 1. TWO-CAR UNIT ON THE BRITISH COLUMBIA ELECTRIC RAILWAY COMPANY'S SYSTEM.

Most tramways and light railways have eventually to face the problem of coping with increasing traffic and this with the minimum of expense. Putting more cars on the line is not a satisfactory solution as it means reduced headway, and a slight traffic block stops many cars, with consequent disorganisation, and in any case there is a limit after which the lines have to be duplicated. Also every car must have its operating staff.

The addition of a trailer car to some or all of the motor cars is not a satisfactory solution, as this reduces the acceleration and schedule speed, or alternatively the motor cars must be over-motored for single car work during slack hours.

The solution adopted in many places is to make all cars motor cars and equip them with multiple-unit control, so that to deal with heavy traffic two or more cars are formed into one unit. The advantages are that these units can run with practically the same headway as single cars, the schedule speed can be maintained, and only one driver is needed. It will be noted that this arrangement is flexible and is well adapted for services where the traffic load is very variable.

To meet the need for suitable equipment for multiple-unit operation, The English Electric Company has developed and put into service in numerous places a light camshaft equipment, the design of which is based on the camshaft equipments which are operating successfully on electric railways all over the world. It has been the Company's aim to provide an equipment cheap in first cost, light in construction—but of ample proportions—easy and simple to maintain, and arranged in weather-proof boxes so that it can be easily housed under the car.

A number of equipments have already been supplied to leading transportation companies, and we give in the following paragraphs a brief description of the control, making special reference to the British Columbia Electric Railway Company Ltd., to whom we supplied twelve equipments of this type early in 1925, and from whom we have recently received an order for a further eight equipments.

The whole of the control gear is mounted in one box with the exception of the master controllers, hand-set circuit-breaker, control switches and resistances. The master controller,

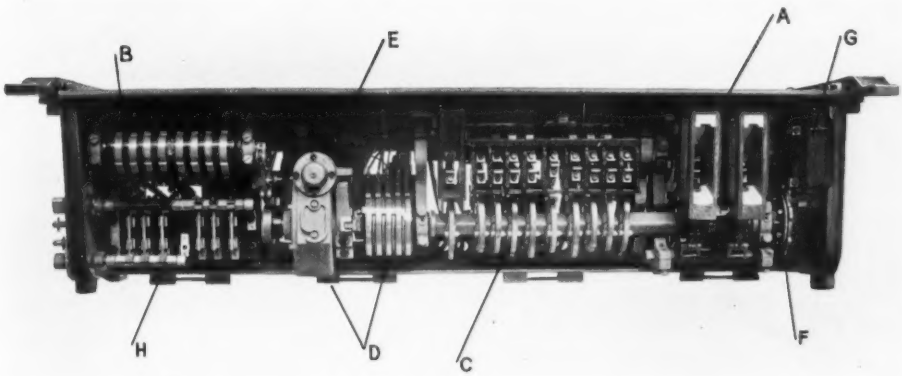


FIG. 2. TYPICAL CAMSHAFT CONTROLLER FOR MULTIPLE-UNIT OPERATION OF TRAMCARS.

circuit-breaker and control switches are mounted in the driver's cab, the control gear case and the resistances being mounted under the car. The control box is of sheet steel on a framework of steel angles which are arranged to carry the individual items of apparatus.

Access to the equipment is obtained through large hinged dust-proof covers which are lined with asbestos felting, and are secured to the case by strong spring catches. Special regard has been paid to accessibility, and it is possible to remove any piece of gear without disturbing the remainder.

Figure 2 shows a typical camshaft controller case with the covers removed. The photograph shows :—

A.—Line Breakers.
B.—Reverser.
C.—Camshaft.
D.—Position Regulator and Driving Gear.
E.—Camshaft Motor.
F.—Current Limit Relay.
G.—Cam-motor Relay.
H.—Motor Cut-out Switch.

The line breakers are of the Company's cam-operated type, in which adequate contact pressure is maintained by the use of steel cams on the contactor shaft, operating against heavy springs. The cams maintain a constant pressure on the contacts independently of the line voltage, and correct operation is assured through a toggle link and holding coil which forms an interlock, preventing the line breakers being closed by the cams until the control circuit is correctly energised.

The breakers are fitted with powerful magnetic blow-outs and these, in conjunction with arc chutes of special design, enable all overloads to be dealt with efficiently. In normal operation the line breakers open the main power circuit when the master controller handle is brought to the off position, but they also deal with normal overloads through an overload relay which is arranged to trip the line breaker control circuit. For heavy overloads a hand-set circuit-breaker is provided, although the line breakers are capable of dealing with a short-circuit current if the occasion arises. The circuit-breaker also provides a means of isolating the power and control circuits.

The reverser is of the solenoid-operated type. The two operating coils are set in tandem and operate the main power contact rocker and control contact rocker through an operating link. The coil to be energised in order to set the reverser for forward or reverse running is determined by the position of the reverser key on the master controller. An electrical interlock is provided so that until the reverser is correctly thrown the line breaker control circuit cannot

be energised, and the camshaft is thus unable to rotate. The power and control drums are accurately turned, and the fingers carefully bedded to ensure that good contact is made. A reverser of this type is shown in Fig. 3.

The contactor camshaft is driven by means of a small shunt-wound motor, through a ball clutch and single reduction gearing. This camshaft carries ten steel cams which open and close the resistance contactors in correct sequence. The contactors, with one exception, do not break current, and by reason of the mechanical interlocking it is not necessary to provide magnetic blow-outs. The transition contactor, however, is so provided in order to deal with the out-of-balance current when passing from series to parallel. As can be seen from the accompanying illustrations, the absence of blow-outs makes for accessibility in inspection, and it considerably reduces maintenance.

At the driving motor end of the camshaft is mounted the position regulator; this is a drum switch which revolves with the camshaft and ensures that the position of the camshaft always corresponds with the position of the master controller handle and the current limit relay. The drum switch is of the dummy segment type, and steel fingers with copper tips bear on the control segments.

At the other end of the camshaft is the current limit relay; this is of the "English Electric" cam-operated type, and is so arranged that the camshaft is prevented from rotating when the main motor current is in excess of a predetermined maximum. The operating cam, which is made of special steel, is mounted on the camshaft, and has nine notches cut in the face to correspond to the five series and four parallel notches on the camshaft. The cam contact lever is held against the face of the operating cam with a spring tension of 30 lbs., so that the relay is quite unaffected by vibration arising under working conditions. A suitable tensioning spring is provided in order that the current limit relay may be set to operate at a predetermined accelerating current.

FIG. 3. SOLENOID-OPERATED REVERSER.

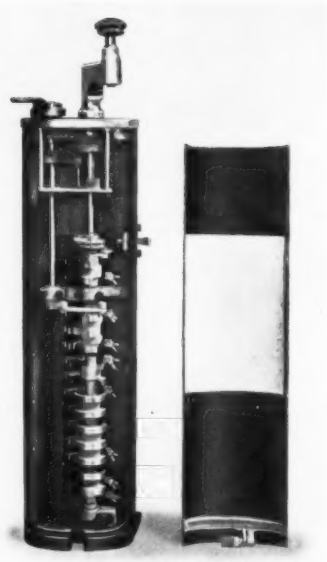


FIG. 4. MASTER CONTROLLER.

The motor cut-out switch consists of simple knife switches, and is so arranged that it can be operated from the side of the car by means of a long operating rod and ratchet handle. In the event of a motor breakdown it is not necessary to open the controller case to cut out the defective motor.

Fig. 4 shows a standard master controller arranged for automatic acceleration, with the

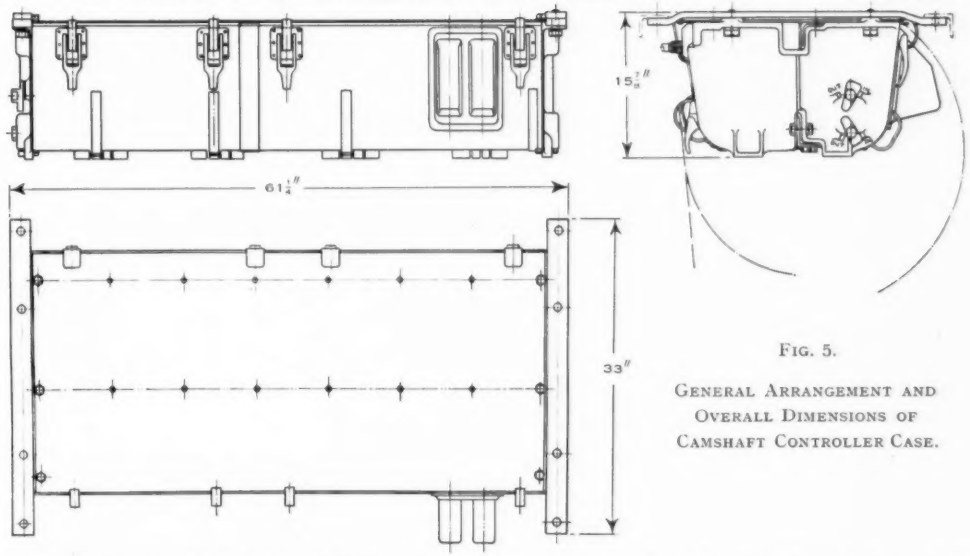


FIG. 5.

GENERAL ARRANGEMENT AND OVERALL DIMENSIONS OF CAMSHAFT CONTROLLER CASE.

front cover removed; its design follows standard "English Electric" practice. The controller fingers are hard copper stampings riveted to phosphor bronze springs and provided with adjusting screws. The contact drum has cast brass segments clamped to a mica-insulated square steel shaft, and these segments are turned to form a true cylinder on which are mounted renewable copper wearing strips.

Some details of the standard equipment, and particularly of the method of working and the sequence of operations, will now be given.

The master controller is provided with a main handle, a reversing lever and an advance lever, interlocked with each other in the usual way. The main handle has three operating positions, first series, full series and full parallel, and the reversing lever has two operating positions, for "ahead" and "reverse" respectively. The advance lever, the purpose of which is described later on, has one operating position, but is spring biased to remain normally in the "off" position.

The camshaft controller is fitted with contactors to give five notches in series and four notches in parallel.

The method of starting is to place the reversing handle to the "ahead" position and then move the main handle right round to "full parallel" position; the camshaft will then automatically notch up under the control of the current limit relay, the accelerating current of the main motors being thus maintained between predetermined limits. The operation of the various parts occurs in the following sequence :—

(1) The reverser is set.

(2) The line breaker holding coils are energised and, by means of auxiliary contacts, set the camshaft motor for rotating the camshaft forward.

(3) The camshaft turns towards the first notch, closing the line breakers. The operating arm of the current limit relay is raised by its cam and forces the control arm towards the holding magnet. The main current is now flowing through the coil of the holding magnet, and the control arm is therefore held up independently of the operating arm.

(4) When the camshaft reaches the first notch position, the operating arm of the current limit relay is released by the cam, and the contacts between the operating arm and control arm are broken, thus de-energising the camshaft motor relay and stopping the camshaft.

(5) When the main current falls to the prescribed lower limit, the control arm of the current limit relay is released and the circuit of the camshaft motor relay again made. The camshaft then advances to the next notch in a similar manner.

In this way notching up proceeds automatically to the full parallel position.

(6) If the car refuses to start owing to gradient or overloading, the advance lever should be placed in the "on" position ; this will advance the camshaft one notch independently of the current limit relay. If this is not sufficient the camshaft may be advanced further notches by alternately placing the advance lever in the "off" and "on" positions. Each movement to the "on" position gives one notch on the camshaft. As the advance lever only gives one notch forward at each operation of the lever, sudden overloading of the motors is prevented. Further, if the advance lever is not allowed to return to the "off" position, it has no further effect on the operation of the camshaft, which continues to notch up under control of the current limit relay.

If, instead of putting the main handle to "full parallel" it is left at one of the intermediate positions, the contactors will automatically notch up, but only so far as to correspond with that position, further movement of the camshaft being stopped by the breaking of the camshaft motor relay circuit by contacts on the position regulator.

Upon the master controller being returned to the "off" position, the line breakers open, thus reversing the camshaft motor and returning the camshaft to the "off" position. In the event of failure of the current supply, the line breakers open, due to the release of the operating links, but the camshaft does not return to the "off" position until current is restored. The line breakers, however, are not set for closing (even if the master controller be in the "on" position) until the camshaft arrives at the "off" position.

The apparatus which we have described is suitable for operation on pressures up to 600 volts D.C., and the gear will control two or four motors at this voltage. Fig. 5 shows the overall dimensions and arrangement of the main controller case.

FIG. 6. TWO-CAR UNIT ON THE BLACKPOOL-FLEETWOOD TRAMWAYS SYSTEM.

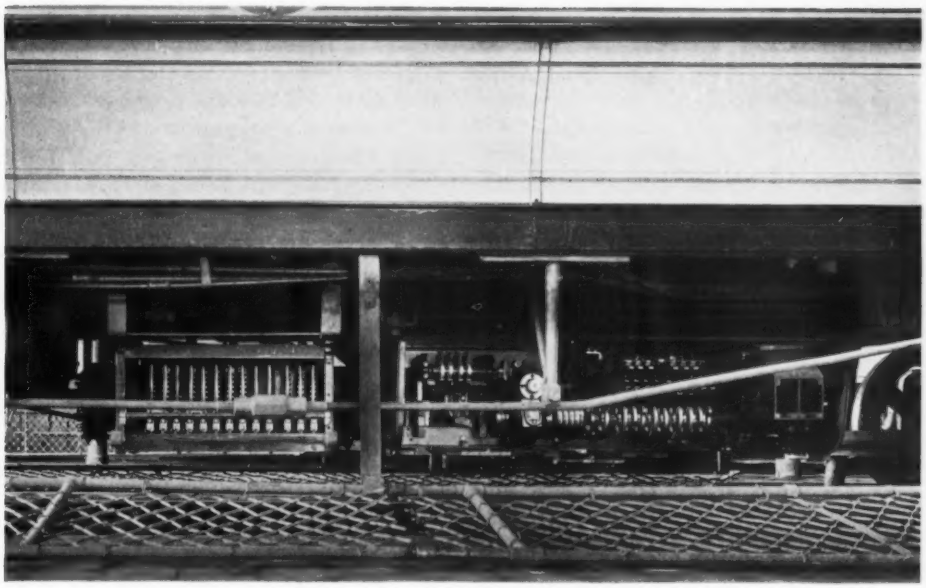


FIG. 7. CAMSHAFT CONTROLLER EQUIPMENT ON BLACKPOOL-FLEETWOOD CAR.

Before the new equipment was placed on the market, two trial equipments were tested out thoroughly on the Blackpool-Fleetwood Tramway system, through the kind permission of the General Manager. The equipments were continually under observation during this period, and after completion of the test they were completely dismantled and carefully examined, and it was found that only minor modifications were necessary before the new type of apparatus was finally standardised. Fig. 6 shows a view of the two cars coupled for multiple-unit operation, and Fig. 7 the equipment mounted on the underframe ; the accessibility of the gear on the underframe will be noted. The trial sets of control gear were arranged to operate on a 500-volt D.C. line, and to control the existing motor equipments, each of which consisted of two 45 H.P. motors.

Earlier in this article reference was made to the British Columbia Electric Railway Co. Ltd. This well-known Company operates a system of electric cars in Vancouver and the surrounding suburbs, and, in common with most operating

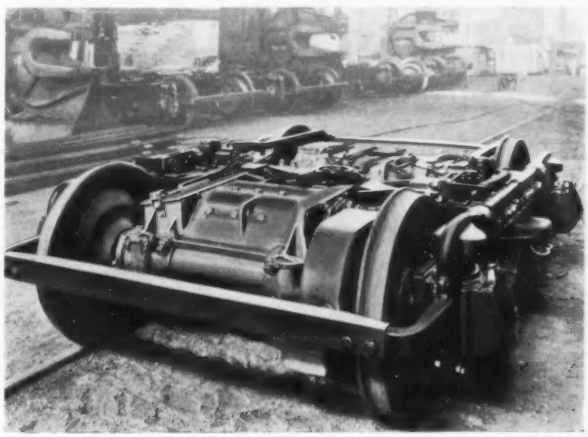


FIG. 8. BOGIE TRUCK FOR BRITISH COLUMBIA CAR.

companies, has been faced with the problem of dealing satisfactorily with rush-hour traffic. It was not considered desirable to endeavour to meet these conditions by adding trailer cars to the existing motor cars, more especially as there are severe grades up to 8 per cent., and it was finally decided to obtain equipments suitable for multiple-unit operation. The question was referred to American traction equipment manufacturing companies, and to The English Electric Company Limited, through its associated Canadian Company, and an order was finally placed for six "English Electric" car equipments, *i.e.*, twelve equipments in all, in December, 1924, each consisting of 4 DK.83B motors, rated at 65 H.P. on 600 volts, and camshaft control equipment; the car bodies and trucks were supplied by the Canadian Car and Foundry Company. Each car is arranged with single-end control and is capable of single-unit operation or multiple-unit operation as desired, the cars being coupled through an automatic coupler of the air and electric type. The cars weigh complete 46,400 lbs. and the length overall is 48 ft. 8 ins. with seating accommodation for forty-eight passengers.

Fig. 1 is a view of a two-car unit, the control equipment being seen faintly on the underframe, and gives some idea of the pleasing appearance of the cars. Fig. 8 shows a bogie truck with motors mounted.

Fig. 9 shows the control equipment case, starting resistances and control resistance, the equipment being generally similar to that described in the foregoing. Fig. 10 shows the arrangement of the gear in the driver's cab and gives a good indication of the small space occupied by the apparatus.

These equipments have now been in continual operation for some nine months, and recently this Company has been favoured with a further order covering equipments for four two-car trains.

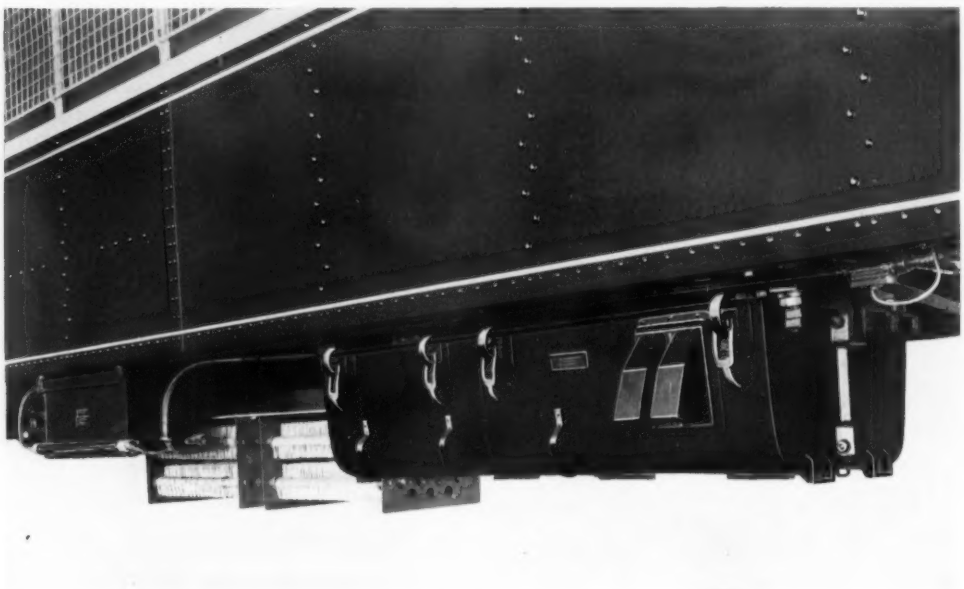


FIG. 9. CAMSHAFT CONTROL EQUIPMENT ON A CAR OF THE BRITISH COLUMBIA ELECTRIC RAILWAY CO., LTD.

Equipments similar to those which we have described are now operating in Sydney and Adelaide, in Australia, and on several light railways in Japan, and from recent reports they are all operating well.

Multiple-unit operation for urban and interurban street car service has been developed extensively both in U.S.A. and in the Dominions. Up-to-date little progress in this direction has been made in the United Kingdom, but the transport requirements in many districts indicate that before long something more will be required than the single-car units which have dealt with the traffic heretofore. It is felt that the experience gained in this class of apparatus places this Company in an exceptionally advantageous position for dealing with this development at home, and for extending its activities overseas.

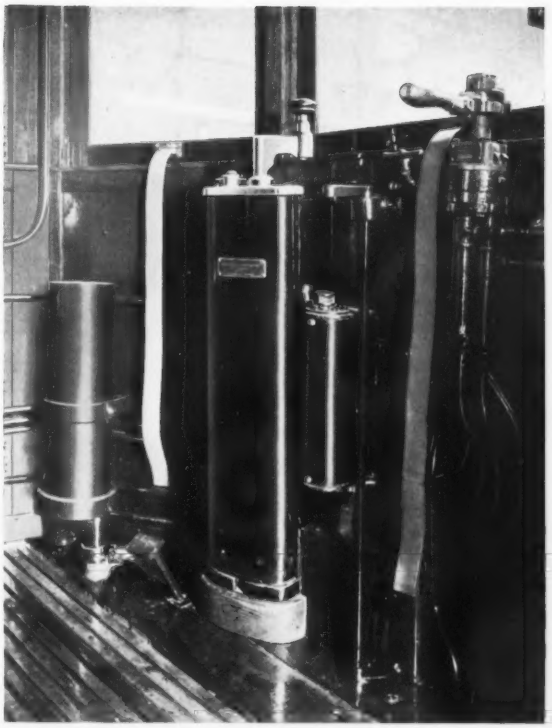


FIG. 10. CONTROL GEAR IN DRIVER'S CAB—BRITISH COLUMBIA ELECTRIC RAILWAY CO., LTD.

In conclusion, we wish to thank the Blackpool-Fleetwood Tramways and the British Columbia Electric Railway Company, Ltd., for their kind permission to publish the information regarding these equipments, and also for the photographs of the rolling stock in service.